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**USERS GUIDE FOR THE TOPSIDE IONOSPHERIC
PLASMA MONITOR (SSIES, SSIES-2 AND SSIES-3)
ON SPACECRAFT OF THE DEFENSE
METEOROLOGICAL SATELLITE PROGRAM
(DMSP).**

VOLUME I: TECHNICAL DESCRIPTION

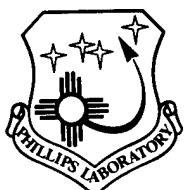
F. J. Rich

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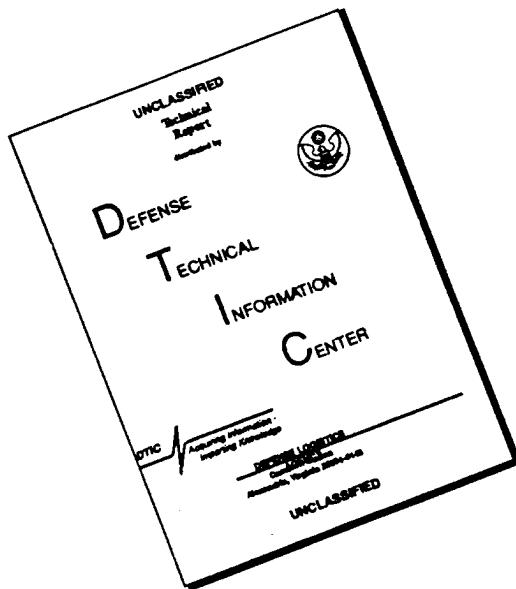
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**Users Guide for the Top Side Ionospheric
Plasma Monitor (SSIES, SSIES-2 and SSIES-3)
on Spacecraft of the Defense Meteorological
Satellite Program (DMSP)
Volume I: Technical Description**

1. Scope

This report describes the Topside Ionospheric Plasma Monitor instruments (acronym SSIES, SSIES2 and SSIES3) for technical users of the data. Throughout this report, the acronym SSIES is generally used to refer to all three of the instruments since that have the same purpose and function in a very similar manner. We consider a technical user to be any person or organization using the geophysical quantities derived from these instruments to assist in determining the state of the space environment. The prime technical user is the Air Force Space Forecast Center, Falcon AFB, CO, which will use the data for now-casts and forecasts of the space environment.

These instruments have been created for use by the U.S. Air Force for monitoring the state of the environment in the near-Earth space on a "near real-time" basis. This report is written to support efforts to make the best possible use of the data for the U.S. Air Force. The data from this instrument are available to the world-wide science and technology community through the National Geophysical Data Center of NOAA/U.S. Department of Commerce. The non-Air Force community is encouraged to provide feedback to the Air Force concerning the finding of uses and potential uses of these data. Thus, this report supports the efforts of non-Air Force scientists and technical personnel in using this data to understand how the Solar-Terrestrial environment works.

While this report covers many details about the Topside Ionospheric Plasma Monitor instruments, it is not comprehensive. Many details, especially those not directly related to the nature of the data, will be found in other documents that are listed in the reference list of this report. Users are encouraged to seek out these other documents are needed. If users have questions that cannot be answered in this or other documents, they are encouraged to contact the technical personnel at the Geophysics Directorate of Phillips Laboratory (PL/GPSP) and at the Center for Space Science at the University of Texas at Dallas (UTD/CSS).

If data from this set of sensors are obtained from NGDC/NOAA, the user is not restricted by the U.S. Air Force in the manner in which the data is used. However, there are areas where the meaning of the data can be misunderstood. Users are strongly encouraged to discuss their results with the technical personnel at PL/GPSP and UTD/CSS before the results are submitted for publication in the open scientific literature.

2. Background

2.1 Summary of the Defense Meteorological Satellite Program

The satellites of the Defense Meteorological Satellite Program (DMSP) are a series of low-altitude (835 km), polar-orbiting satellites. Their primary mission is to observe the tropospheric weather. The primary sensor system used to accomplish this mission is the Operational Linescan System (OLS), a high resolution (2.8 km), white-light and infrared imaging system. The first DMSP satellite was flown in the early 1960's. Since then, the size of the DMSP satellites, the quality of the instrumentation, and the number of instruments has grown. About 1970, the white-light imager was improved to observe clouds illuminated by moonlight. This improvement also made it possible to make images of the aurora, or the Northern and Southern Lights. This was the beginning of the secondary mission of DMSP to monitor the space environment. The space environment is important to the Air Force because of the various ground-based and space-based systems that can be affected by the space environment.

Table 1 Characteristics of DMSP Spacecraft

	Block 5D-2	Block 5D-3
Orbit	458 n.mi. (848 km), 98.8 Deg inclination, 0.001eccentricity, Sun-synchronous	458 n.mi. (848 km), 98.8 Deg inclination, 0.001eccentricity, Sun-synchronous
Design Lifetime	4 years	5 years
Booster	Atlas and Titan II	Titan II
Weight - Total On-Orbit /Payload	1792 Lbs / 519 Lbs	2278 Lbs / 592 Lbs
Avg. Power - Total/Payload	537 W / 218 W	630 W / 281
Attitude Control	Local Vertical +/- 0.01 Deg.	Local Vertical +/- 0.01 Deg

The present series of DMSP spacecraft configuration is known as Block 5D which started with Flight 1 (or F1) in 1976 of Spacecraft 1 (or S1). Since then, while the basic spacecraft design has remained the same, incremental changes in the size and details of the design have allowed more payload for both the tropospheric mission and the space environment mission. A newer, larger spacecraft frame, designated Block 5D-2, was used for S6 through S14 and another expansion of the spacecraft frame, designated Block 5D-3, has been used for S15 through S20. Table 1 gives some physical parameters of the spacecraft and Table 2 lists the complement of the 5D-2 and 5D-3 missions.

Table 2 Sensor Complement of Recently Flown and Planned DMSP Spacecraft

Spacecraft / Flight (Launch Date)	Sensor Complement
S9 / F8 (20 June 87)	OLS, SSIES(s/n 003), SSJ4, SSMT1, SSBX-M, SSMI
S8 / F9 (02 Feb 88)	OLS, SSIES(s/n 001), SSJ4, SSMT1, SSBX-M, SSK
S10 / F10 (01 Dec 90)	OLS, SSIES(s/n 002), SSJ4, SSMT1, SSBX-2, SSMI
S11 / F12 (29 Aug 94)	OLS, SSIES2(s/n 002), SSJ4, SSMT1, SSMT2, SSBX-2, SSMI, SSM (body-mounted)

S12 / F11 (28 Nov 91)	OLS, SSIES2(s/n 001), SSJ4, SSMT1, SSMT2, SSBX-2, SSMI
S13 / F13 (TBD)	OLS, SSIES2(s/n 003), SSJ4, SSMT1, SSMT2, SSBX-2, SSMI, SSM (body-mounted), SSZ
S14 / F14 (TBD)	OLS, SSIES2(s/n 004), SSJ4, SSMT1, SSMT2, SSMI, SSM (body-mounted), SSZ, SSBX
S15 / F15 (TBD)	OLS, SSIES2(s/n 005), SSJ4, SSMT1, SSMT2, SSMI, SSM (boom-mounted), SSz
S16 / F? (TBD)	OLS, SSIES3, SSJ5, SSMIS, SSM (boom-mounted), SSF, SSUSI, SSULI
S17 / F? (TBD)	OLS, SSIES3, SSJ5, SSMIS, SSM (boom-mounted), SSF, SSULI, SSUSI
S18 / F? (TBD)	OLS, SSIES3, SSJ5, SSMIS, SSM (boom-mounted), SSF, SSULI, SSUSI
S19 / F? (TBD)	OLS, SSIES3, SSJ5, SSMIS, SSM (boom-mounted), SSF, SSULI, SSUSI
S20 / F? (TBD)	OLS, SSIES3, SSJ5, SSMIS, SSM (boom-mounted), SSF, SSULI, SSUSI

2.2 Solar-Terrestrial Environment

For our purpose, the near-Earth environment consists of a neutral atmosphere and an ionized atmosphere. The neutral atmosphere consists of the following layers: the troposphere (0 to 12 km altitude), the stratosphere (12 to 45 km altitude), the mesosphere (45 to 85 km), the thermosphere (85 km to 1000 km) and the exosphere (above 1000 km altitude). Meteorology is concerned with processes in the first two layers of the neutral atmosphere. The Earth's ionized atmosphere is composed of the ionosphere (70 km to 1000 km), the plasmasphere (1000 km to 4 Re for magnetic latitudes less than 60 degrees), and the magnetosphere (from the top of the plasmasphere at low latitude and from the top of the ionosphere at high latitudes to approximately 8 Re on the dayside and to approximately 1000 Re on the nightside). Just beyond the near-Earth environment is the interplanetary environment, which is dominated by a high speed (300 to 800 km/sec), hot ($> 100,000 ^\circ\text{K}$), tenuous ($3 \text{ to } 30 \text{ cm}^{-3}$) plasma streaming out from the Sun's corona. From time to time, this plasma stream, known as the solar wind, is enhanced by coronal mass ejections, which are related to giant flares in the Sun's chromosphere, and by high speed streams from coronal holes. Solar flares are clearly visible in white light, X-rays and other parts of the electromagnetic spectrum. Thus, observations of the Sun's surface can aid in the prediction of coronal mass ejections that might impact the Earth. Coronal holes cannot be detected except with X-ray imagers on spacecraft or rocket payloads located above the Earth's atmosphere. Thus, high speed streams can impact the near-Earth environment without any warning. The only knowledge of a high speed stream is that they tend to last for months and they tend to rotate with the rotation of the Sun's surface.

The ultimate source of all of the structure of the near-Earth space environment is the Sun. As shown in Figure 1, the sun generates energy and propagates that energy in many different forms. Electromagnetic radiation (light) from the Sun in the visible, infrared and longer wavelengths of the spectrum passes through the ionosphere and thermosphere without interactions. Ultraviolet (wavelengths less than 400 nm) and shorter wavelengths of the spectrum interact with the thermosphere to deposit energy and to ionize the neutral atoms and molecules. The intensity of the white light and near infrared radiation from the Sun is very close to a constant. There is a small variation in the intensity received at the Earth due to the slight variation of its orbit which brings the Earth slightly closer to the Sun in the Northern Hemisphere's winter. The ultraviolet radiation varies with the 11 year cycle of Sun spots. When the spots are most numerous, the ultraviolet radiation is strongest. This causes an increase in the temperature of the thermosphere and ionosphere and increased

production of ionization. This increases the density of both the neutral and ionized atmosphere above 100 km altitude. During a solar flare event, the Sun's output of ultraviolet and X-ray radiation is enhanced for periods of several hours to several days leading to variations in the thermosphere and ionosphere.

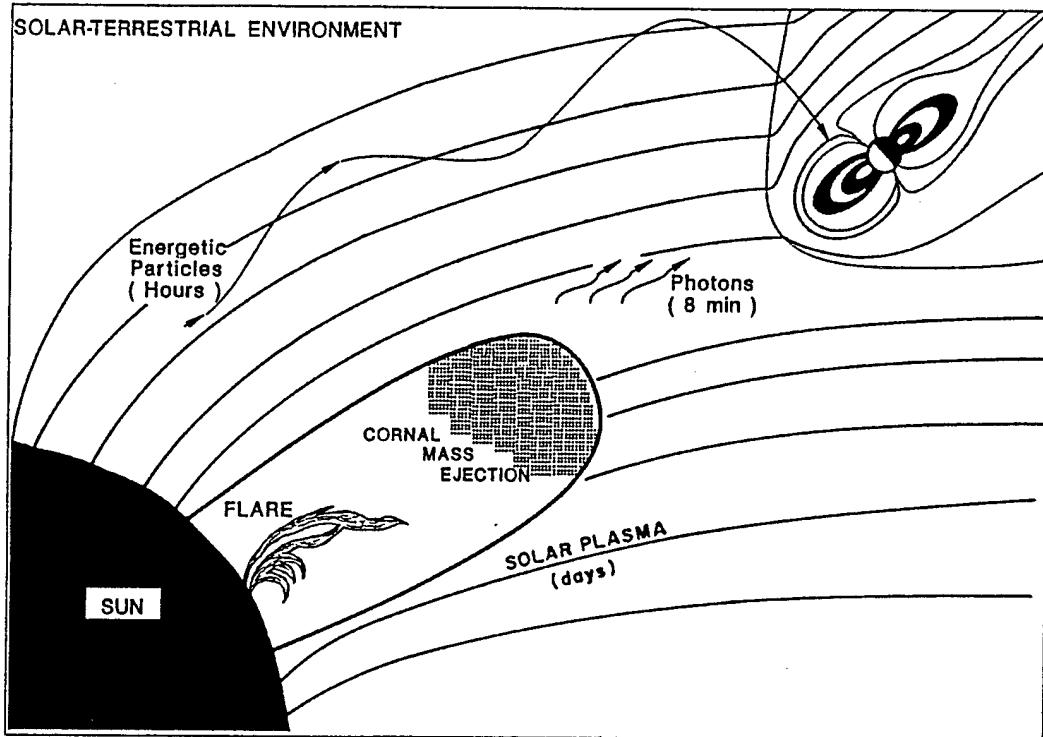


Figure 1. The Solar-Terrestrial Environment

There is a steady stream of ionized gas flowing out from the Sun's outer layer or corona. This plasma flow into interplanetary space (known as the solar wind) affects the thermosphere and ionosphere. Embedded within the solar wind plasma is a fragment of the Sun's magnetic field (known as the Interplanetary Magnetic Field or IMF). Because ionized particles are affected by the Earth's magnetic field, the process of interaction is very complex. The majority of the solar wind particles are detoured around the region dominated by the Earth's magnetic field (known as the magnetosphere) and continue to flow outward. Through an interaction between the IMF and the Earth's magnetic field, some of the energy from the solar wind is transferred to the near-Earth space environment.

This report cannot devote much room to describing the many and complex ways in which energy is transferred from the Sun to the Earth and the near-Earth environment. Users needing to know more about the Solar-Terrestrial environment are encouraged to seek out reference material. There is an abundance of reference material; we recommend starting with the *Handbook of Geophysics and the Space Environment*¹ produced by the Air Force Geophysics Laboratory (now re-organized into PL/GP).

2.3 Ionosphere-Magnetosphere Environment

The Earth's ionosphere does not receive particles or energy directly from the solar wind because it is shielded by its magnetic field. The region dominated by the Earth's magnetic field is called the magnetosphere and the boundary between the interplanetary environment and the magnetosphere is called the magnetopause. This boundary is a magnetic structure maintained by charged particles flowing along the boundary.

Figure 2 shows the elements of the Earth's magnetosphere. Except for the cusp region, all solar wind particles must flow around the magnetosphere. The cusp is a weak spot on the magnetopause near the noon meridian. The cusp is a

boundary between the dayside geomagnetic field lines which are compressed but closed (connected to the Earth at both ends) and the elongated field line of the geomagnetic tail. There are two cusps; one in each hemisphere. The configuration of the geomagnetic field in the cusps allows solar wind particles to enter the magnetosphere with little modification. Many solar wind particles entering the cusp are returned back into the interplanetary environment by magnetic mirroring forces, but some enter the magnetosphere and ionosphere. The cusps map to a small region in the ionosphere along the noon meridian and near 78 degrees magnetic latitude. High energy ($E > 50$ keV) particles from the sun are also blocked from direct entry to the ionosphere by the geomagnetic field, but their paths are better described by single particle interactions than by the fluid interaction of the solar wind. Extremely high energy particles ($E > 20$ MeV) and cosmic rays reach the ionosphere and top of the atmosphere with little restriction from the geomagnetic field.

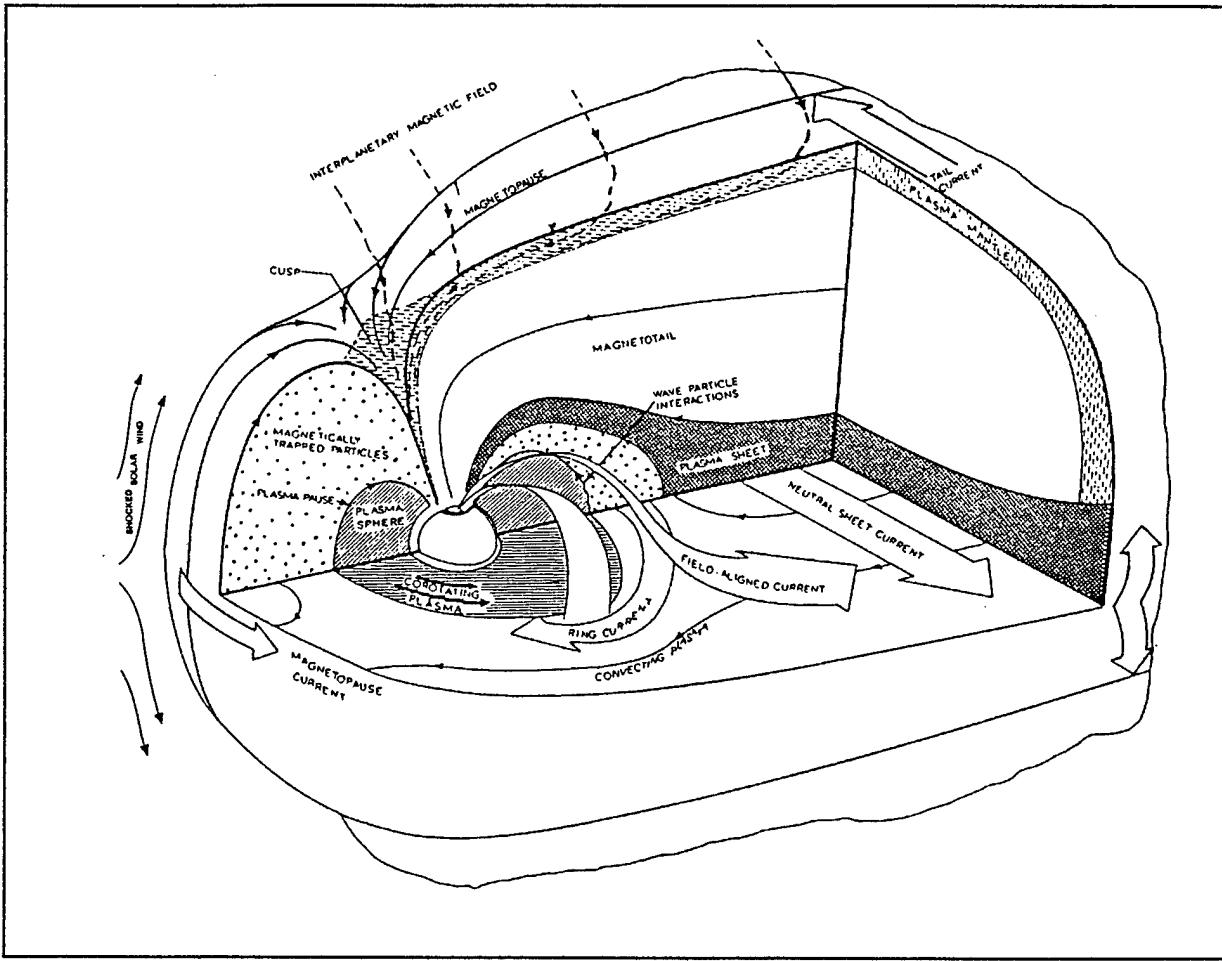


Figure 2. Earth's Magnetosphere and Its Interactions With the Interplanetary Medium

Because of the interaction between the Earth's magnetic field and the interplanetary medium, the magnetosphere is pulled out into a "tail" behind the Earth to a distance of approximately 1000 Re. Some particles may enter the magnetosphere at the end of the tail and some particles may leak through the magnetopause as they flow along the sides of the magnetosphere. The biggest energy transfer from the solar wind is in the form of a quasi-static electric field across the magnetosphere from the dusk magnetopause to the dawn magnetopause and by the energization of cold (1000 - 3500 °K or 0.1 to 0.3 eV) ionospheric plasma into hot (1 to 50 keV) plasma in the plasma sheet of the magnetosphere. The hot plasma returns to the ionosphere in a ring from approximately 12° to 20° of latitude from the Earth's magnetic poles. This ring is the auroral oval, and the light generated by the impact of the hot plasma on the cold thermosphere is the aurora or Northern and Southern Lights. While the aurora is present continuously, there are times when the flow of plasma is greatly enhanced for a period of 20 minutes to an hour and the aurora brightens greatly. These periods are called geomagnetic substorms. When the energy flow from the interplanetary medium is much greater than normal, the substorms will be

initiated so often that the bright aurora will be generated continuously. Often this enhanced substorm activity causes the aurora region to be wider in latitude and at lower latitudes than normal. Such a period of enhanced substorms is a geomagnetic storm.

2.4 Space Environment Mission of the DMSP System

Many Department of Defense (DoD) assets are affected directly or indirectly by the near-Earth space environment. For example, the Global Positioning System (GPS) consists of a group of spacecraft in Earth orbit at high altitude and high inclination with radio transmitters that give the spacecraft position and clock to very high precision. The GPS signals are received on the ground by hand-held devices that give the precise location of the receiver. The GPS signals must pass through the ionosphere, which will alter the signal. If the receiver does not compensate for the effect of the ionosphere, the precision of the receiver's output is degraded. Air Weather Service (AWS) provides military GPS users with the information needed to correct the signals for the ionospheric effects. One of the major sources of information about the state of the ionosphere on a daily basis is the information coming from the space environment sensors on the DMSP spacecraft. In fact, all DoD spacecraft are directly affected by the near-Earth space environment. Data from DMSP spacecraft together with data from solar observing stations and other data sources can help determine the daily variations in the level of hazard to space vehicles.

2.4.1 Purpose of Topside Ionospheric Plasma Monitor

The Topside Ionospheric Plasma Monitor (acronym SSIES) measures the thermal plasma at the location of the DMSP spacecraft. In particular, the SSIES measures the ion/electron density (n_i and n_e), variations in the ion density (Δn_i) along the spacecraft path down to a scale size of 10 m, the ion and electron temperature (T_i and T_e), the portion of the thermal ion population composed of hydrogen (H^+), helium (He^+) and oxygen (O^+) ions, and the ions' bulk motion relative to the Earth's surface. Since thermal plasma can be affected by surface charges of a few volts, the SSIES also monitors the charge on the spacecraft's ground relative to the ambient plasma.

The geophysical parameters determined from the SSIES measurements are used to determine the condition of the ionosphere and magnetosphere. Since the SSIES is embedded in the ionosphere, its measurements are a direct determination of the state of part of the ionosphere. Since the high latitude ionosphere is electrically connected to the magnetosphere along geomagnetic field lines, the bulk ion flows observed by SSIES are a proxy for the large-scale electrical fields in the magnetosphere.

The SSIES measurements have the advantage that all latitudes are observed each orbit (101 minutes) and, with two spacecraft operating, four local times are observed. This set of measurements has the limitation that the observed parameters are obtained at only one altitude and that variations in the environment with time scales less than an orbital period cannot be measured. To obtain an accurate picture of the ionosphere, the SSIES data is combined with other data sources such as density-height profiles obtained from ground-based ionosondes. Since there are never enough ionosondes and other data stations in the world to give a complete picture, the SSIES data is also combined with climatological models of the ionosphere.

2.4.2 Other Instruments Observing the Space Environment

The Air Weather Service uses data from DMSP spacecraft for determining, on an hourly basis, the state of both the tropospheric environment and the space environment. The other space environment instruments flown on or planned for DMSP spacecraft are briefly described below. For its tropospheric meteorological mission, AWS also draws data from ground stations that it operates, stations operated by NOAA and many other sources. Likewise, for determining the space environment, AWS draws data from many sources in addition to the DMSP spacecraft. AWS maintains the ground-based SOON (Solar Observing Optical Network) and RSTN (Radio Solar Telescope Network) stations to observe the level of activity on and near the Sun's surface. AWS also maintains ground-based, digital ionosonde stations to observe the ionosphere above the stations and magnetometer stations to observe the ionosphere-magnetosphere environment. In addition, AWS receives space environment data from NOAA which comes from both NOAA operated spacecraft and ground-based stations and stations operated by other agencies and other countries. In the late 1990's, AWS will receive real-time data from NASA's WIND spacecraft which will be observing the solar wind.

2.4.2.1 Precipitating Energetic Particles (SSJ4 & SSJ5)

The Precipitating Energetic Particle Spectrometer (acronym SSJ4 and its functional update SSJ5) measures ions and electrons with energies from 30 eV to 30 keV on downward flight paths within a few degrees of local vertical. The precipitating electrons are an important source of production of ionospheric plasma in the auroral oval region and significantly modify the conductivity of the auroral ionosphere. For the winter, nighttime ionosphere, the precipitating particles are the dominant source for plasma production in the auroral ionosphere. Collisions between the precipitating electrons and neutral atoms is the energy source for the visible emissions, known as the aurora, at altitudes approximately from 100 km to 400 km. At low latitudes, the SSJ4 detects trapped radiation belt particles ($E > 1$ MeV) but it is not calibrated for this function. At latitudes higher than the auroral zone, the SSJ4 measures solar wind particles that enter the magnetosphere somewhere in the tail behind the Earth.

The SSJ4 (and its predecessors SSJ2 and SSJ3) have been part of the DMSP system since the early 1970's. The SSJ4 is provided to DMSP by Phillips Laboratory (PL/GPSP). The SSJ2 and SSJ3 were provided by Aerospace Corp.

2.4.2.2 Vector Magnetometer (SSM)

The vector magnetometer (acronym SSM) measures the strength and direction of the total geomagnetic field at the spacecraft location in the range of $\pm 64,000$ nT with a sensitivity of better than 50 nT. This total field is a vector sum of the magnetic field created by the Earth's internal magnetic field and a disturbance magnetic field created by electrical currents flowing between the ionosphere and magnetosphere. The disturbance magnetic field changes on a time scale of a few seconds to a few hours.

The primary Air Force requirement is to monitor the state of the ionosphere. By subtracting a model of the Earth's internal field from the SSM data, a measurement is obtained of the disturbance magnetic field created by electrical currents flowing along geomagnetic field lines from the ionosphere to the magnetosphere. These "field-aligned" currents are generally confined to the auroral zone. In effect, the SSM is an ammeter. The SSM data together with the SSIES data and/or SSJ4 data can determine the energy input to the auroral ionosphere by Joule heating. Joule heat is the energy released by an electric current flowing through a finite resistor element. The ionosphere acts much like the heating element of an electric stove, the magnetosphere acts like the electric power station, and the geomagnetic field lines act as the transmission wires. The SSM data determines the quantity of electric current flowing between the ionosphere and magnetosphere; the SSIES data determines the electric field perpendicular to the field lines which drives the current through the E-layer; and the SSJ4 data helps to determine the ionospheric conductivity. From Ohm's law, the electrical energy input to the auroral zones can be determined.

In addition to measuring the disturbance magnetic fields, the SSM data can also be used to measure the portion of the geomagnetic field originating inside the Earth's surface. Since the internal magnetic field is changing rapidly ($\sim 10^{-2}$ % per year) on a geologic scale, there is a great need to re-determine the field every few years. On the other hand, the internal field changes very slightly on the time scale of a DMSP spacecraft lifetime. As a result, the magnetic field must be measured to extremely high (better than 10 nT) precision. While the SSM sensor has the required precision, spacecraft noise has proven extremely detrimental to using the SSM data for determining the internal magnetic field. Because spacecraft noise rapidly decreases in magnitude with increasing distance from the source, this problem will be solved for future SSM sensors by placing the sensor at the end of a 5 m boom beginning with spacecraft S15.

The first SSM was flown on F7 as a proof of concept instrument. Starting with F12, the SSM will be on all future DMSP spacecraft. The SSM is provided jointly by Phillips Laboratory (PL/GPSG) and NASA / Goddard Space Flight Center.

2.4.2.3 Whitelight/Infrared Imager (OLS)

The Operational Linescan System makes images with an oscillating, scanning radiometer that operates in two spectral intervals; visible (400-1100 nm) and infrared (8,000-13,000nm). By contrast, the imaging system on the TIROS spacecraft have three infrared channels and no visible channel. While many technical details of the OLS have changed over the years, the functional description of the system has not changed since it was described by Eather². Nighttime visible data are obtained in the spectral band 450 - 950 nm using a photo-multiplier tube. Only with the photo-multiplier operating at

night can the system detect the glow of the aurora. When the full Moon is illuminating the Earth's surface, dim auroral features tend to merge with features of the moon-lit clouds. Subtraction of the clouds using the IR data can retrieve dim aurora, but the images produced at AFGWC prior to 1992 make no effort to do the subtraction.

The most commonly available resolution of the data (known as Thermal-Smooth or Light-Smooth) has a pixel size of 2.8 km^2 (1.5 n.mi.^2) on the ground at nadir. Each scan line covers a swath 2960 km wide (nadir $\pm 57.85^\circ$). In the middle third of the scan, the aperture is square, but for the left and right thirds of the swath, the aperture is closed slightly in the direction of the scan in order to keep the pixel's footprint on the Earth as close to square as possible. The visible data is sent down with a 6-bit resolution or 64 gray levels. The system has an automatic gain control (AGC) which is usually allowed to change the gain during the scan. When part of the ground in a scan is in sunlight and part is in shadow, the AGC will allow the radiometer to return useful information in both parts of the scene, but generally not along the sunset line. The state of the AGC is not returned with the radiometer outputs; so it is impossible to get the absolute radiance of each pixel.

The OLS is designed and built by Westinghouse Defense Systems of Westinghouse Electric Corp., Baltimore, MD.

2.4.2.4 Ultraviolet Imagers (SSUSI & SSULI)

To gain more information about the ionosphere below the DMSP spacecraft, two systems will be added to the sensor complement to measure the radiance of the atmosphere at ultraviolet wavelengths.

The Limb-Scanning Ultraviolet Imager Sensor System (SSULI) is provided to DMSP by the Naval Research Laboratory.

The Nadir-Scanning Ultraviolet Imager and Spectrometer Sensor System (SSUSI) is provided to DMSP by the Applied Physics Laboratory of Johns Hopkins University.

2.4.3 Operational Models

To utilize space environment data from ground-based and space-based sensor systems, a series of computer program must be constructed to receive the data and return parameters that are useful to the personnel of the Space Forecast Center and, in turn, to the customers of AFSFC. The computer programs can be put into two groups. The first group of programs converts the raw telemetry data (counts, volts, etc.) into geophysical parameters (ion density, current density, ion drift velocity, etc.) The second set of programs obtains data from the spacecraft data, from ground-based data and from climatological data to produce parameters useful to operators of space-based systems. This collection of computer programs is needed because no one sensor system can produce all of the parameters that are needed for specifying and forecasting the space environment. Even with inputs from all the sensor systems, there are often gaps in the desired parameters. These gaps are a combination of temporal gaps, spatial gaps and gaps in sensitivity and/or type of parameters. The computer models of the space environment are built to accept as much or as little information as may be available and to make the best possible estimate of the space environment. Each of the computer models listed below is tailored to specify and/or forecast only part of the space environment.

At the present time, the models below are still in a transition stage between development and full implementation. Outputs from the SSIES system or any other sensor system are (or will be) input to more than one of the models. It is anticipated that as experience is obtained with these operational models, more and/or better uses of the space environment data will be found and the models will be modified as needed.

2.4.3.1 MSM and MSFM

The conditions of the space environment near geosynchronous orbit, where several DoD systems are located, can be determined by a time-dependent, physical model of the inner magnetosphere. This model is known as the Rice Convection Model (RCM) because it was developed at Rice University and is described by Harel et al.³ and Spiro et al.⁴. The model is initialized with boxes located at 30 Re behind the Earth in the magnetosphere. Each box represents the plasma in a magnetic flux tube. The majority of the plasma in the box is near the equatorial plane of the magnetosphere, but the model includes the connection of the flux tube to the ionosphere. The model is stepped forward in time to allow the boxes to convect in toward the Earth. At each time step new boxes are added at the boundary behind the Earth. The boxes are

removed from the system as they flow out through the dayside portion of the magnetopause. After a sufficient number of time steps, the system is at equilibrium. At that point, realistic variations in the geophysical parameters can be introduced and the model will respond to the inputs in a manner similar to the real magnetosphere.

The amount of computation time required to operate the full model is enormous. To use the Rice Convection Model in an operational environment, a second program known as the Magnetospheric Specification Model (MSM) and its extension, the Magnetospheric Specification and Forecast Model (MSFM) have been created. MSM and MSFM contain a set of tables containing the outputs of the RCM under specified conditions. The MSM and the MSFM determine the history of the space environment over the past 24 to 72 hours from the data sources available, determine what mixture of outputs from the RCM are most applicable to the current environment and then output parameters interpolated from the tables. The procedures of the operational models are described by Bales et al.⁵ The SSIES provides information about the magnitude of the cross-polar-cap potential which drives the speed of the magnetospheric convection in the model and the distribution of the cross-polar-cap potential which affects the direction of the magnetospheric convection.

2.4.3.2 PRISM

The Parameterized Real-time Ionospheric Specification Model (PRISM) is based on parameterized physical models rather than statistical or climatological models. It uses near real-time data from ground-based sources and satellite-based sources, such as SSIES and SSUSI, to adjust the parameterized models. The adjustment parameters in PRISM vary with location and can be determined from a wide variety of data representing most of the near real-time data that is available and will become available to the Space Forecast Center in the next year or two.

Four separate physical models are used in PRISM: a low-latitude F layer model, a mid-latitude F layer model, a combined low-and mid-latitude E layer model, and a high-latitude E and F layer model. To achieve sufficient computational speed, the models were parameterized in terms of geophysical parameters. The parameterization process involved the production of "databases" for various values of the geophysical parameters and the generation of semi-analytical representations of the databases. The base ionospheric model, representing "theoretical climatology," is adjusted on the basis of near real-time data by determining corrections to eight profile parameters at the data locations. A weighted average based on distance is used to produce a global "correction field" that specifies the adjustments to the base climatological model to provide a specification of the current state of the ionosphere.

2.4.3.3 VSH

The Vector Spherical Harmonic (VSH) model specifies and forecasts the density, temperature, composition and winds in the upper atmosphere. The model is valid for the altitude range of 90 to 1500 km, for all latitude, for all local times and for all seasons. The model is based on the Thermosphere-Ionosphere General Circulation Model (TIGCM), which is a computer simulation of the upper atmosphere with multiple cells of the atmosphere linked together with differential equations. TIGCM was developed at the National Center for Atmospheric Research (NCAR)⁶ and requires a very large, very fast computer. VSH was developed at the University of Michigan. It truncates the output of the TIGCM without significantly sacrificing accuracy. VSH uses real-time indices of the geospace environment. The VSH model uses an empirical formula to select the TIGCM parameter most appropriate for the input indices. If any of its input indices are missing, it will use climatological estimates of the indices. The VSH model requires modest computer resources and is appropriate for use in a real-time environment.

2.4.3.4 Ionospheric Scintillation Specification and Prediction System

The Ionospheric Scintillation Specification and Prediction System (ISSPS) is a collection of programs to assess the effects of ionospheric scintillations. Ionospheric scintillation is defined as the fluctuations in the phase and intensity of radio signals passing through the ionosphere. These effects can interfere with the operation of USAF communications and surveillance systems. ISSPS was developed by Northwest Research Associates Inc. for operational use by AWS. The system can run in one of two modes, climatological or real-time. In climatological mode, the estimates of scintillation are calculated from simple inputs (date, time of day, SSN [Sunspot Number] and K_p). In real time mode, the estimates are calculated from data from the DMSP SSIES data and from the ground-based TISS data. The ISSPS consists of five programs: SBCKL (reads SSIES data), GBCKL (reads TISS data), IONSAM (Ionospheric Scintillation Affects Model), WBMOD (WideBand Model) and GISIM (Gridded Ionospheric Scintillation Model).

3. OVERVIEW OF TOPSIDE IONOSPHERIC PLASMA MONITOR SYSTEM

The purpose of the SSIES system is to measure the state of the ionospheric plasma at the location of the DMSP satellite. The data are used to determine total electron content (TEC) and other ionospheric/ magnetospheric parameters that can affect the Air Force's ability to operate. To do this, the SSIES consists of three ion sensors, an ion sensor assembly and ground plane, one spherical electron sensor mounted on a rigid boom, two electronics boxes mounted inside the Equipment/Service Module of the spacecraft, and the wiring assemblies needed to connect everything. Figure 3 shows the deployed DMSP spacecraft with the ion sensor array attached to the bottom (Earthward) portion of the section of the truss assembly facing the forward direction. For spacecraft with ascending node in the morning sector, the ion array is attached to the +Z side of the truss and is facing the +Y spacecraft direction. For spacecraft with ascending node in the afternoon/evening sector, the ion array is attached to the -Z side and is facing the -Y spacecraft direction. For Block 5D-3 spacecraft, the ion array will be moved to the Precision Mounting Platform (PMP) in order to get away from a search-and-rescue transmitter/receiver boom which will be mounted on the Truss and will extend along the -Y direction.

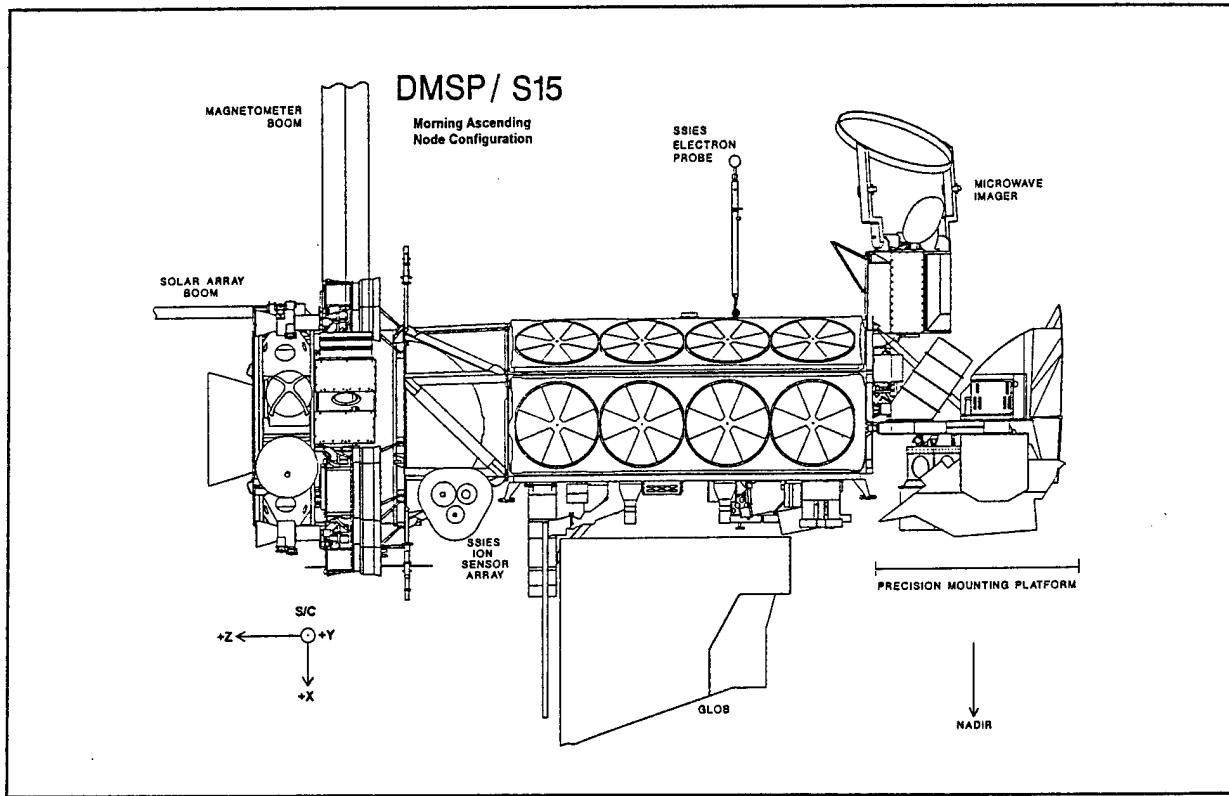


Figure 3. Outline of the DMSP Block 5D-3 Spacecraft in Its Deployed Configuration

3.1 Geophysical Parameters

The SSIES sensors are tailored to the anticipated environment at 840 km altitude and at all latitudes, all local times, all seasons and all phases of the sunspot cycle. Typically, this environment is composed of three ion species; hydrogen (H^+), helium (He^+) and oxygen (O^+). Under all conditions and in all regions, except the winter mid-latitude region, O^+ constitutes 95% to 99.9% of the ions. At mid-latitudes, the nighttime ion temperatures are of the order of $1000\text{ }^{\circ}\text{K}$ (.086 eV) and daytime ion temperatures are of the order of $3000\text{ }^{\circ}\text{K}$ (.26 eV). Nighttime electron temperatures are of the order of $1200\text{ }^{\circ}\text{K}$ (0.10 eV) and daytime electron temperatures are $3500\text{ }^{\circ}\text{K}$ (0.30 eV). These temperatures increase and decrease with solar activity. In the regions of strong energy transport from the magnetosphere to the ionosphere, the ion and electron temperatures increase and are spatially structured. For an ion temperature of $2000\text{ }^{\circ}\text{K}$, O^+ , He^+ and H^+ have thermal velocities of 1.4 km/s, 2.9 km/s, and 5.7 km/s, respectively. At $2000\text{ }^{\circ}\text{K}$, the electron thermal velocity is 240 km/s. Plasma densities usually are between 10^3 and 10^6 cm^{-3} . The electron thermal motion is much faster than the ion thermal

motion because thermal scales as the inverse inverse of the square root of a particle's mass. Table 3 lists the geophysical parameters that SSIES, SSIES2 and SSIES3 are designed to measure.

Table 3 Geophysical Parameters Measured by SSIES and SSIES 2

Parameter	Sensor	Range	Sensitivity	Accuracy	Data Rate
v_H, v_V (horizontal & vertical ion drift)	DM	± 2.7 km/sec, $n_i > 3 \times 10^3 \text{ cm}^{-3}$, $n[H+] + n[He+] < 30\% n[O+]$	12 m/sec	± 50 m/s	6 /sec
n_i (total ion density)	SM	$10^6 - 10^2 \text{ cm}^{-3}$	0.01	$\pm 10\%$	24 /sec
n_i (total ion density)	RPA	$10^6 - 10^1 \text{ cm}^{-3}$	0.01	$\pm 10\%$	1 / 4 sec
n_i (total ion density)	DM	$10^6 - 10^3 \text{ cm}^{-3}$	0.02	$\pm 30\%$	1 / 2 sec
Δn_i (variations in ion density)	SM	$10^5 - 10^{-3} \text{ cm}^{-3}$	$10^{-4} n_i$	TBD	1 sec
$n[H+]$ or $n[He+]$ (density of H+ or He+ ions)	RPA	$10^6 - 10^2 \text{ cm}^{-3}$	$n[H+] + n[He+] > 10\% n[O+]$	$\pm 10\% n_i$	1 / 4 sec
$n[O+]$ (density of O+ ions)	RPA	$10^6 - 10^2 \text{ cm}^{-3}$	1% of n_i	$\pm 10\% n_i$	1 / 4 sec
$T_i = T[O+]$ (temperature of O+ ions)	RPA	500 - 9,000 °K	± 50 °K	± 200 °K or $\pm 10\%$	1 / 4 sec
v_D (downrange component of ion drift velocity)	RPA	± 5 km/sec	100 m/sec	± 200 m/s	1 / 4 sec
$V_p^{(1)}$ (plasma potential w.r.t. SSIES ground plane)	RPA	± 5 V	0.1 V	0.5 V	1 / 4 sec
V_p (plasma potential w.r.t. DSMP ground)	SENPOT ⁽²⁾	0 - 28 V	0.05 V	0.2 V	1 sec
V_p (plasma potential w.r.t. SSIES ground plane)	EP	± 3 V	0.1 V	0.5 V	1 / 4 sec
T_e (electron temperature)	EP	500 - 9,000 °K	± 50 °K	± 200 °K or $\pm 10\%$	1 / 4 sec
n_e (electron density)	EP	$10^6 - 10^2 \text{ cm}^{-3}$	0.1	$\pm 50\%$	1 / 4 sec
$\Delta v^{(4)}$ (variations in ion drift velocity)	DM ⁽³⁾	$10^3 - 10^{-1} \text{ m/s}$	10^{-1} m/s	TBD	1 / 2 sec

Notes:

(1) Plasma potential measured with respect to aperture potential

(2) Not available on SSIES S/N1 (F9).

(3) Available only on SSIES2.

(4) Available only when DM FIBA mode is on.

3.2 The SSIES System

The functional block diagram of the SSIES is shown in Figure 4. The system consists of the ion retarding potential analyzer (RPA), the ion drift meter (DM), the total ion trap (SM), the spherical electron sensor (EP), the sensor potential control system (SENPO), the Main Electronics Package (MEP) and the DSM electronics package. All of the ion sensors are planar, electrostatic analyzers, often referred to as Faraday cups. The aperture of the incoming particles is a plane. The ions pass through a series of flat screens that have applied electrostatic potentials. The ions are then collected on a flat metal plate. The current to the plate is detected and reported as telemetry data. The planar geometry is appropriate for measuring thermal ions since the spacecraft speed is supersonic with respect to the ions. For the electrons, the spacecraft speed is subsonic and a spherical geometry is more appropriate for collecting and measuring them. The spherical electron sensor, often referred to as a Langmuir probe, is separated from the spacecraft by a short boom because the Sun creates an envelope of low energy electrons within a few centimeters (a Debye length or two) of the spacecraft surface. Much of the information given in this section can also be found in reports by Holt⁷ and Greenspan et al.⁸.

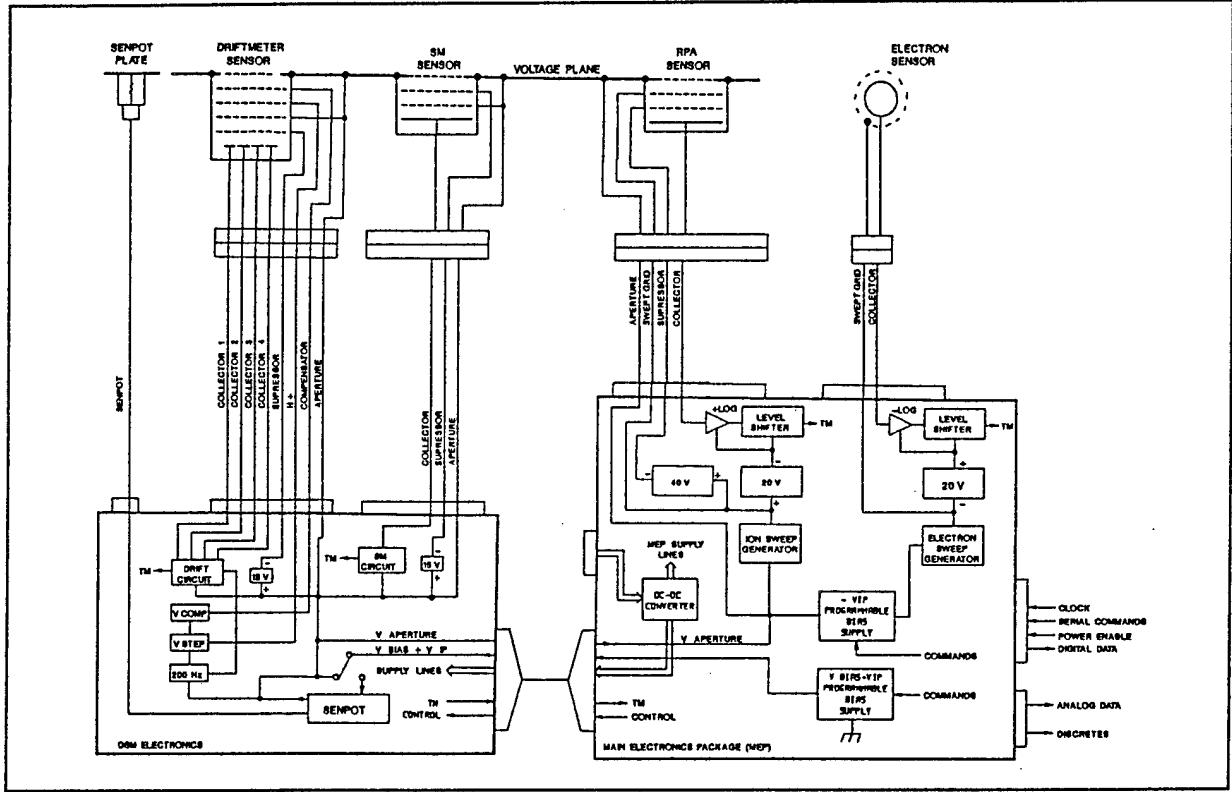


Figure 4. SSIES System Block Diagram (S8/F9 and S10/F10)

3.2.1 The Microprocessor

The SSIES's voltage stepping, mode switching and telemetry handling is controlled by a microprocessor. Earlier and simpler sensor systems were controlled mechanically. In SSIES and SSIES2, the microprocessor is a Texas Instruments SBP9900A microprocessor. Since the microprocessor has more capability than just handling the system housekeeping, the microprocessor also does on-board analysis of RPA and Langmuir probe data. Because of the slow speed of the microprocessor and the criticality of the housekeeping function, the analysis algorithms are simpler than those used in the ground-based processing. On the other hand, the SSIES system generates four times more samples than can be put into the telemetry output buffer and the microprocessor has access to this higher data rate. Analog measurements are converted to 10 bits of digital data; only 9 bits are telemetered. The microprocessor receives 25 current measurements from the Langmuir probe and 149 current measurements from the RPA each second. Twenty-four Langmuir probe measurements

are telemetered and one is discarded. Of the RPA current measurements, 24 are telemetered, and 125 of the 149 samples are averaged in groups of 5 to create 25 samples for the in-flight calculations. The microprocessor program is stored in an EPROM (Erasable, Programmable Read-only Memory). The SSIES microprocessor program cannot be modified in flight. The SSIES2 and SSIES3 microprocessor programs can also run from code sent from the ground and stored in RAM (Random Access Memory) after the sensor has been turned on and initialized by the program in an EPROM.

3.2.2 The Automatic Sensor Potential Control System

To determine the characteristics of the thermal plasma, it is necessary to hold the instrument potential close to the plasma potential. The DMSP satellites have 28 V, negative ground electrical systems. Because the positive contacts on the solar panels are exposed and can attract electrons, a DMSP spacecraft's ground potential tends to range between 18 V and 28 V negative with respect to the plasma when the spacecraft is in sunlight. This poses a problem for the SSIES sensors which are designed on the assumption that their ground potential will be within 2 V of the ambient plasma. The ambient ions and electrons have an energy defined by their random velocity (i.e. temperature), collective velocity (drift velocity) and the potential they fall through as they approach the sensor. For example, if the electron sensor's potential is -1 V, then from an applied voltage of +1 V to +2.5 V the collected electron current will drop rapidly in a manner which tells the electron temperature. The SSIES Langmuir probe has a range of +/- 4 V; if the sensor's ground potential is outside the range of +/- 3 V, then the sensor will not function properly. The SSIES ion sensors are also designed for a potential close to that of the ambient plasma. To make measurements of the thermal plasma parameters possible, the SSIES instrument adjusts the potential between the spacecraft and the Langmuir probe and the ion sensors' ground plane to a potential very close to the plasma potential.

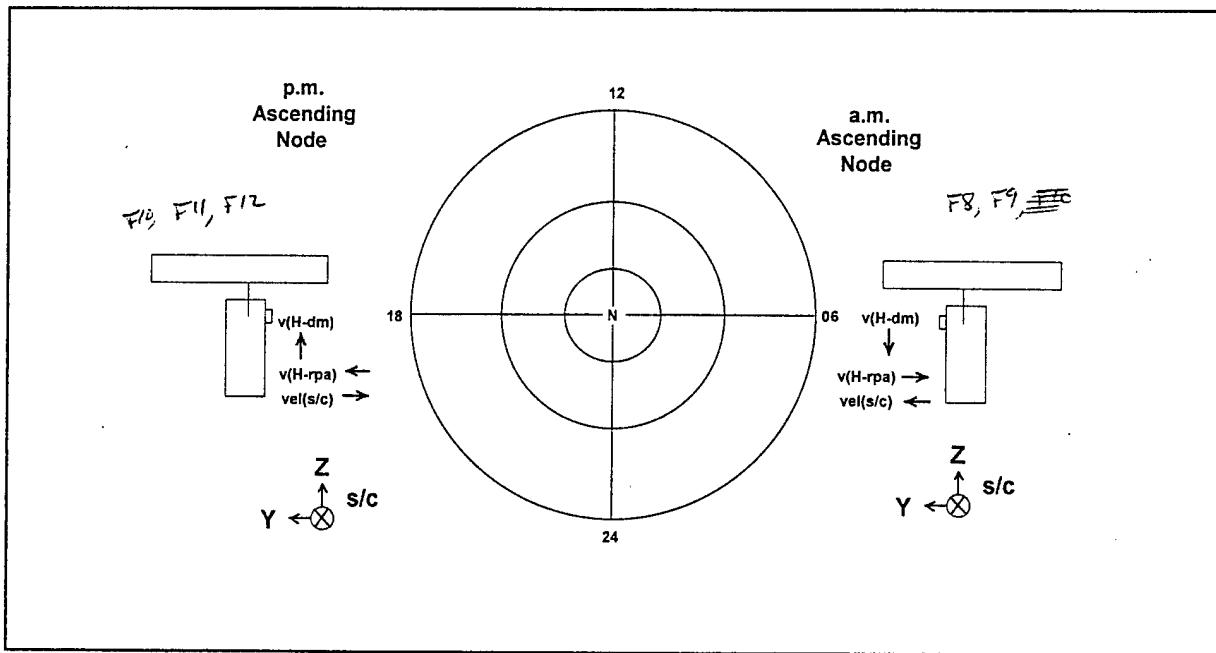


Figure 5. SSIES Coordinates With Respect to Spacecraft and Geographic Directions

There are three different methods that may be used to control the potential of the SSIES sensors; two function automatically. The first uses the instrument's microprocessor to compute an appropriate bias potential from an analysis of the Langmuir probe data. The second method uses an analog circuit called SENPOT to drive the ion sensor ground potential close to the plasma potential¹. DMSP F8 (S9) and F10 (S10) have SENPOT systems, but F9 (S8) does not. Finally, the reference voltages of the ion sensors ($V_{BIAS} + V_{IP}$) and the Langmuir probe may be set by ground command.

3.2.3 The SSIES Coordinate System

The values for ion drift output from the SSIES system are, with respect to coordinates, defined by the ion drift meter and the RPA, not by the spacecraft. The spacecraft coordinates are +X radially down, +Z is parallel to the solar panel boom when deployed and +Y completes the right-handed system. When the ascending node is in the morning sector, the spacecraft's +Y side is facing the ram (the direction of spacecraft motion) and the ion sensor array is mounted on the +Y side as shown in Figure 3. When the ascending node is in the afternoon/evening sector, the spacecraft's -Y side is facing the ram and the ion sensor array is mounted on the -Y side. Bulk ion flow, anti-parallel to the spacecraft velocity, increases the apparent ram velocity into the RPA sensor and defines the positive direction for the RPA's determination of the drift. Bulk flow toward the ion drift meter's B and C plates (as shown in Figure 4) defines the positive horizontal direction for the driftmeter's horizontal flow, and bulk flow toward the ion drift meter's C and D plates defines the positive vertical flow. The positive vertical flow is toward the spacecraft's -X axis (upward). The horizontal flow is toward the -Y spacecraft axis for morning ascending node and toward the +Y spacecraft axis for afternoon/evening ascending node. See Figure 5 for the relationship between the driftmeter's positive flow direction to the spacecraft and geographic directions. In the AFSFC processing program, a value of +1 in the initialization file will yield the directions shown in Figure 5. A value of minus one will reverse the directions when they are sent to the output file.

3.3 The SSIES2 System

The functional block diagram of the SSIES2 system is shown in Figure 6. The SSIES2 system is almost identical to the SSIES system. The differences are:

- (1) In the SSIES2 system, the pre-amplifiers for the analog signals from the ion and electron collection plates have been moved out of the electronics package. For the ion sensors (DM, SM and RPA), the preamps are inside the case of each ion sensor. For the electron probe, the preamp is inside a small box at the base of the EP boom. The preamps were moved to prevent noise from entering the cables between the collector plates and the electronics boxes inside the ESM. In addition, the circuit which generates the SENPOT voltage has been moved to the back of the SM sensor case.
- (2) The SENPOT mode for controlling the potential of the sensors' apertures is the default mode.
- (3) The number of filters for measuring high frequency variations in the SM output has been reduced from 9 to 6, and 6 new filters have been added. The 6 new filters are attached to the DM output.
- (4) The voltage on the collector plate of the RPA does not follow the voltage of the retarding screen. In the SSIES RPA, the varying potential difference between the collector plate and the aperture caused a displacement current in the RPA's output.
- (5) The microprocessor program can be over-written with a new program sent to the spacecraft through the command system. This allows the instrument output to be optimized for changes that were not known about when the program in the EPROM was written.
- (6) The DM H+ retarding grid has been moved to the front of the entrance aperture. This eliminates the need for a compensation grid behind the aperture.

Much of the information about the SSIES2 system can also be found in the report by Holt¹⁰.

The schematic outline of the SSIES2 sensors in Figure 7 shows the sensors in more detail than seen in Figure 3. The view of the sensors seen in this figure is identical to the SSIES sensors. If the back side of the ion sensors were shown, one would see the increased depth of the sensor cases, with respect to the SSIES sensor cases, that contain the pre-amplifiers.

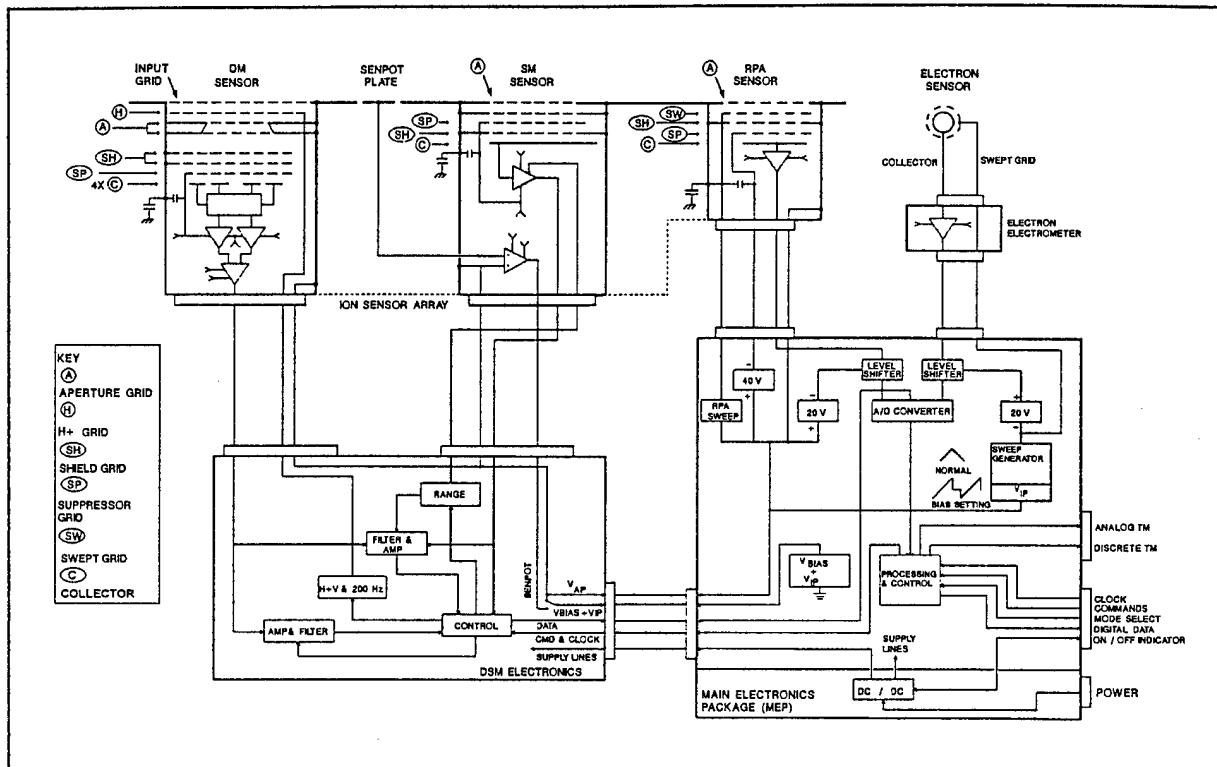


Figure 6. SSIES2 System Block Diagram

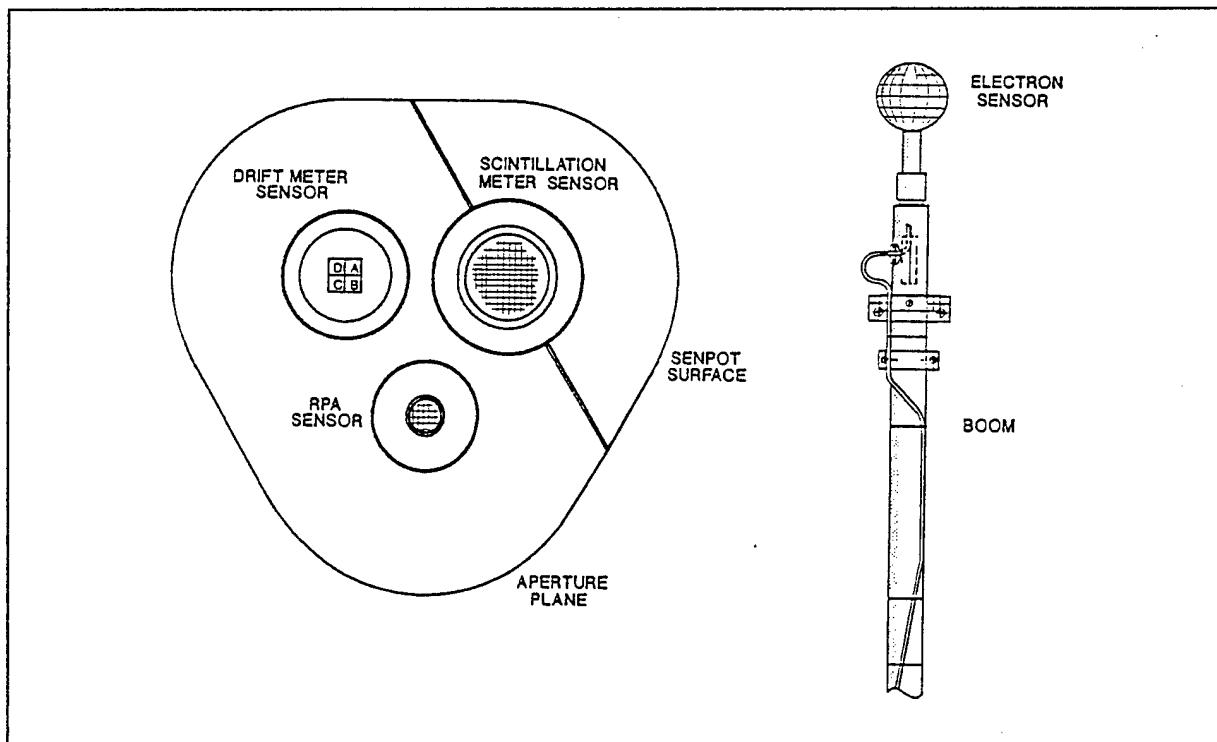


Figure 7. Schematic of the SSIES2 System

3.4 The SSIES3 System

A schematic of the electronics boxes and sensors used for the SSIES3 system is shown in Figure 8. The SSIES3 system measures the same geophysical parameters as the SSIES2 and SSIES, but there are several differences in the construction of the system. Most of the differences have no effect upon the manner in which data are placed into the telemetry or upon the manner in which the data are handled. However, some of the differences do affect the data processing, especially the change to the RPA. The differences are:

- (1) All of the circuits for detecting the analog outputs of the sensors have been moved out of the Main Electronics Package (MEP) and put into the other electronics box. Since the other electronics box handles all sensor outputs and not just the outputs from the DM and SM sensors, that box has been redesignated as the Sensor Electronics Package (SEP). All of this arrangement of electronics has no effect on the manner in which the sensors collect data or in the processing of that data.
- (2) The RPA sensor and its electronics have been redesigned. A cross-sectional view of the RPA sensor is shown in Figure 9. The mechanical design of the RPA sensor is very similar to the mechanical design of the previous RPA sensors. The most significant change is the measuring system for ion current flowing to the collector plate. In the SSIES3 RPA, the measuring system uses a linear electrometer with ranging instead of the single-range, logarithmic electrometer used in SSIES and SSIES2. This gives the instrument a better response at low densities (less than 10^3 ion cm^{-3}). In addition, the retarding voltage steps and range will vary under the control of the onboard microprocessor. In the SSIES and SSIES2, there were a fixed number of steps over a fixed range. Many of the samples put into the telemetry were not useful for analyzing a given piece of data, but were included because they might be necessary for other pieces of data taken at other times. To cover all possible cases, the retarding voltage step size and range were larger than optimum. In the SSIES3, the step size and range are optimized. This puts more burden on the data processing, but will yield better values for the geophysical parameters.

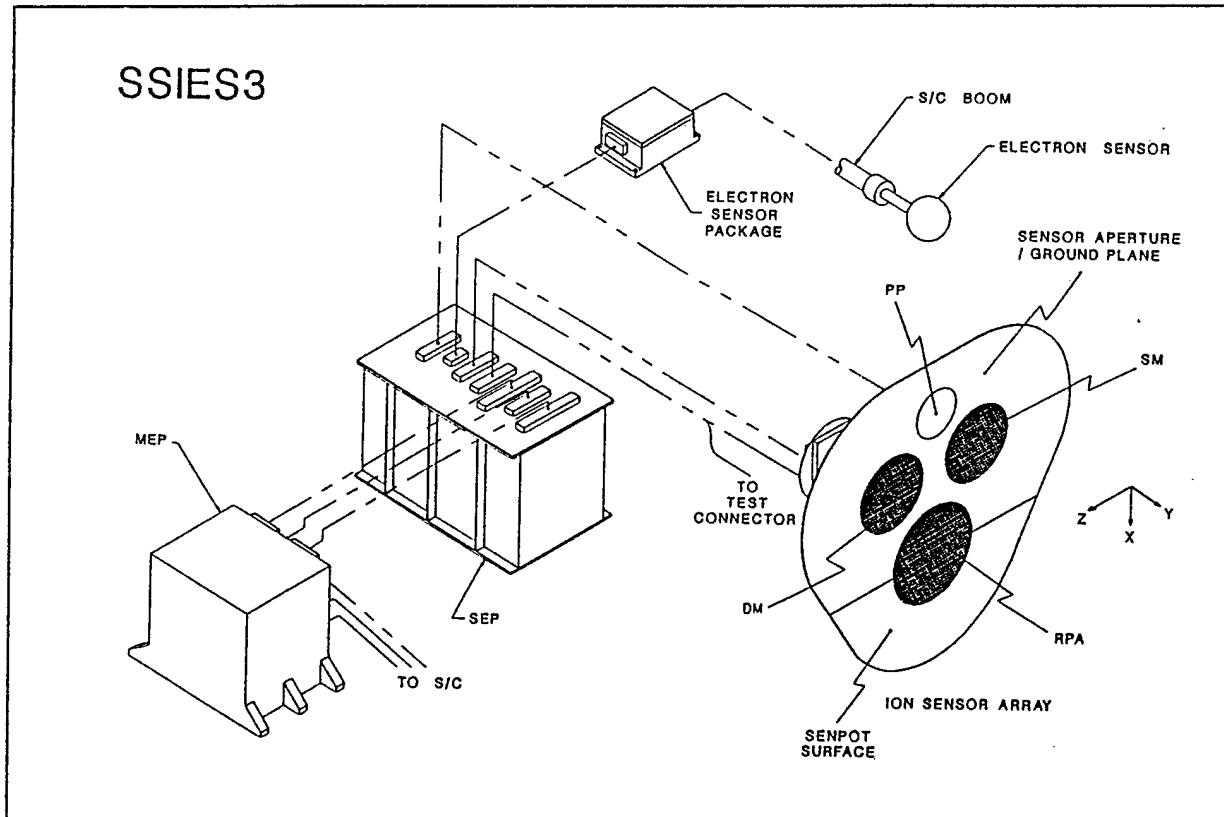


Figure 8. Schematic of the SSIES System

(3) The SSIES3 contains a second electron probe, known as the Plasma Plate (PP). The PP's collecting surface is part of the ion sensor array aperture plane; see Figure 8.

The potential of the RPA with respect to the ambient plasma is a critical parameter in analyzing the RPA data. In the analysis software for SSIES and SSIES2 data, it is assumed that the SENPOT circuit will bring the RPA sensor's aperture to 0 V with respect to the ambient plasma. This assumption is not needed if both O⁺ and H⁺ or He⁺ ions are present in measurable amounts, but that is seldom true. This assumption would not be needed if the potential calculated from the Electron Probe data were accurate to 0.01 V. In fact, the EP potential calculation is only accurate to 0.1 V which is not good enough for the analysis of RPA data. There is also a physical separation between the RPA and EP sensors which may affect the potentials at the two locations and which has not been considered in the potential from the EP data.

(4) The Drift Meter on SSIES3 is mechanically the same as the SSIES2 sensor. A cross-sectional view of the Drift Meter sensor is shown in Figure 10. There are some changes in the sensor's electronics. First, the bandwidth of the analog to digital conversion has been changed to increase the range of velocities the DM will detect to approximately ± 4 km/sec. This will also increase by about 30 percent the amount of an increment of the drift needed for a 1-bit change in the output. A 1-bit change in the output corresponds to a change in the drift velocity of ~ 16 m/sec. There is also a change in the meaning of the DM telemetry data. For SSIES and SSIES2, a "re-zero and offset" technique was employed in the electronics to remove any imbalance in the logarithmic electrometers within the DM electronics. This technique required 24 switching events to obtain 12 samples of normal drift per second. Switching adds noise to the output signal which can render the DM output useless when the ambient density is below about 10^3 cm⁻³. To reduce system noise and make the DM sensitive at lower densities, the SSIES3 reports the ratio of the output from the electrometers without an analog re-zero. The zero-level of the electrometers will be included in the data processing. In addition, the DM FIBA mode which was added for SSIES2 has been removed in SSIES3. To further reduce the switching noise, the SSIES3 DM will automatically reduce the switching to once per second when the ambient ion density detected by the SM sensor falls below a pre-set level. This results in a cycle of 12 horizontal measurements followed by 12 vertical measurements. SSIES2 has a similar mode which is activated only by ground command. When the ambient density rises above the threshold, the DM will resume its normal mode of operating.

(5) The SM sensor is mechanically the same as the SSIES2 instrument. A cross-sectional view of the SM sensor is shown in Figure 11. Electronically, the SM operates the same as the SM sensors in the SSIES and SSIES2 systems for 510 seconds of each 512 second period. For the last 2 seconds of each period, the bias on the suppressor screen is set to exclude ions and allow photoelectrons to be ejected from the collector. This allows a determination of any changes in the characteristics of the collector plate over its lifetime in space. This knowledge may lead to a re-determination of the SM calibration and a more accurate measurement.

(6) The EP sensor has not changed mechanically. The only change to the electronics is the mode of applying a voltage to the outer grid. All of the modes used by the SSIES2 EP have been eliminated except for a mode which is similar to the BS mode. That mode is a cycle of sweeping the voltage applied to the outer grid in one direction for 2 seconds, holding the voltage constant for 2 seconds, sweeping in the opposite direction for 2 seconds and holding the voltage constant for 2 seconds. The measurements of current collected during the 2-second sweeping period are fed out to the telemetry over 4 seconds so that there is only a minor change in the way the EP data is handled in the ground data analysis. That change comes from the sequence of obtaining data internally. For SSIES and SSIES2, the microprocessor receives 25 EP current values and 149 RPA current values per second. The 149 RPA current values are averaged to create 25 values. Then the first 24 of the 25 values are placed into the output telemetry buffer. This results in a slightly uneven spacing of retarding voltages for the values in the telemetry. For SSIES3, each 2-second EP sweep will send 192 current values to the microprocessor. In 4 seconds, 96 points will be sent to the output telemetry. On one direction of sweep, all even numbered samples will be sent and on the opposite sweep direction, all odd numbered samples will be sent. This will result in an even spacing of retarding voltages, but a slight offset of retarding voltages between up and down sweeps.

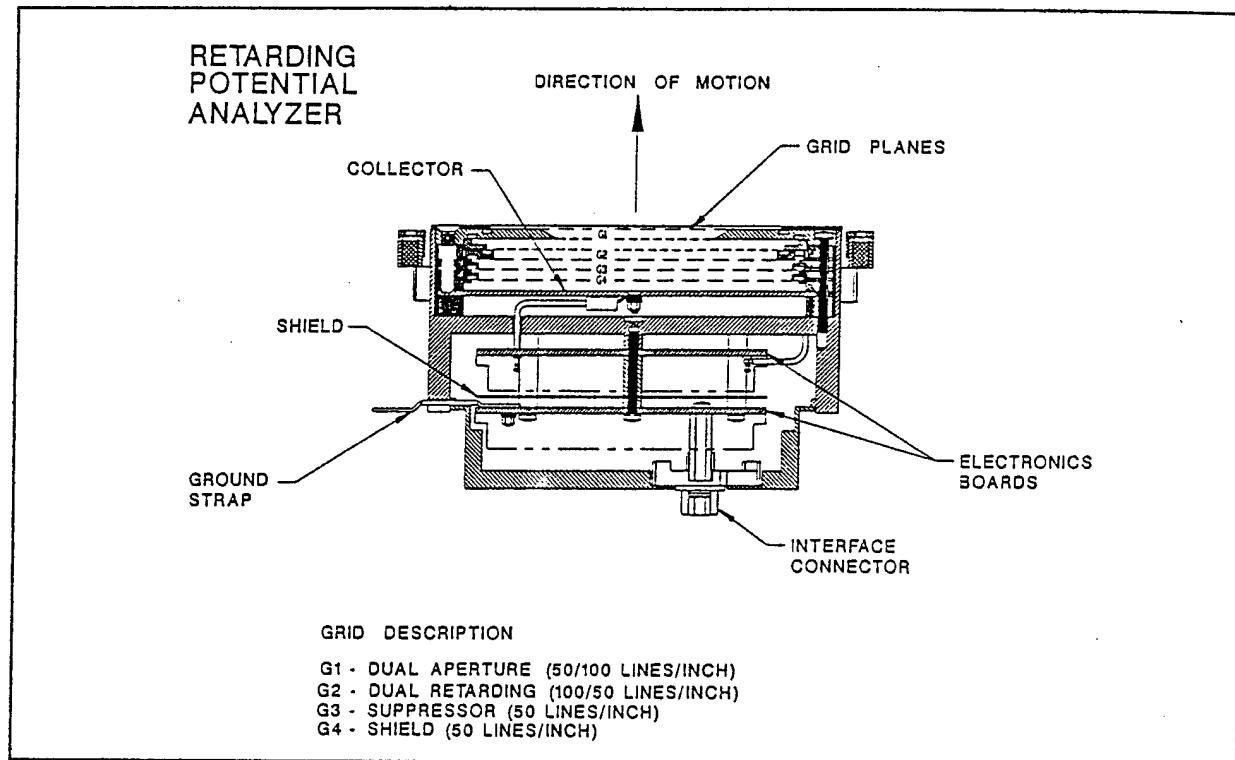


Figure 9. Cross Section of the SSIES3 Retarding Potential Analyzer

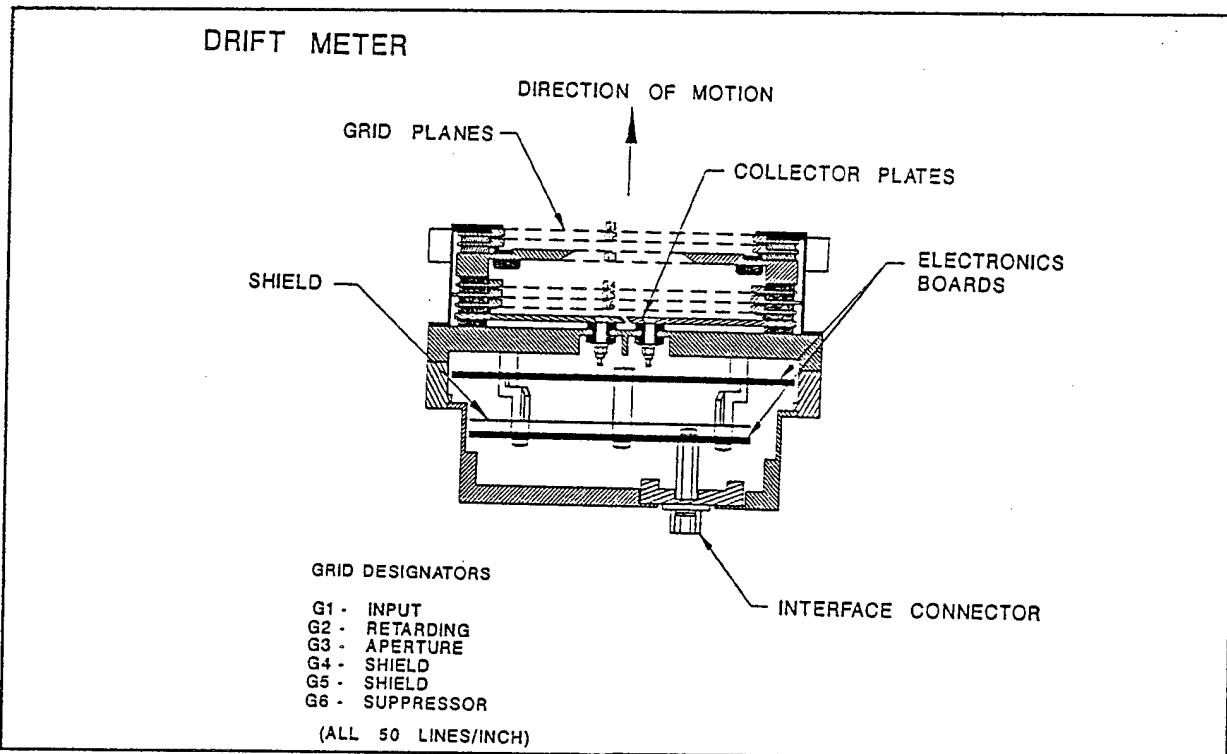


Figure 10. Cross Section of the SSIES3 Drift Meter

(7) The biggest difference in the SSIES3 is the microprocessor and random access memory (RAM). The SSIES and SSIES2 used a Texas Instrument 9900 series microprocessor which was programmed in assembly code. The SSIES3 uses a 1750A microprocessor with more RAM which is programmed in the Ada language. This allows a more complex set of routines for processing data on-board. The new microprocessor does not affect the way raw SSIES3 data is processed on the ground. The most significant difference is that the results of microprocessor calculations in the telemetry are more accurate.

(8) Each 2048 seconds, the RPA and EP data in the telemetry stream are overwritten with status information about the RPA and EP sweep monitors for 8 seconds. This will result in a loss of RPA and EP data for 8 seconds. This status dump and subsequent loss of data for 8 seconds can be disabled by ground command, if necessary.

The specifications for the SSIES3 system are given in a report written and published by the SSIES-3 Program Office¹¹ at Lockheed Sanders of Nashua, NH. At the present time, there is no published report describing the "as built" SSIES-3 system.

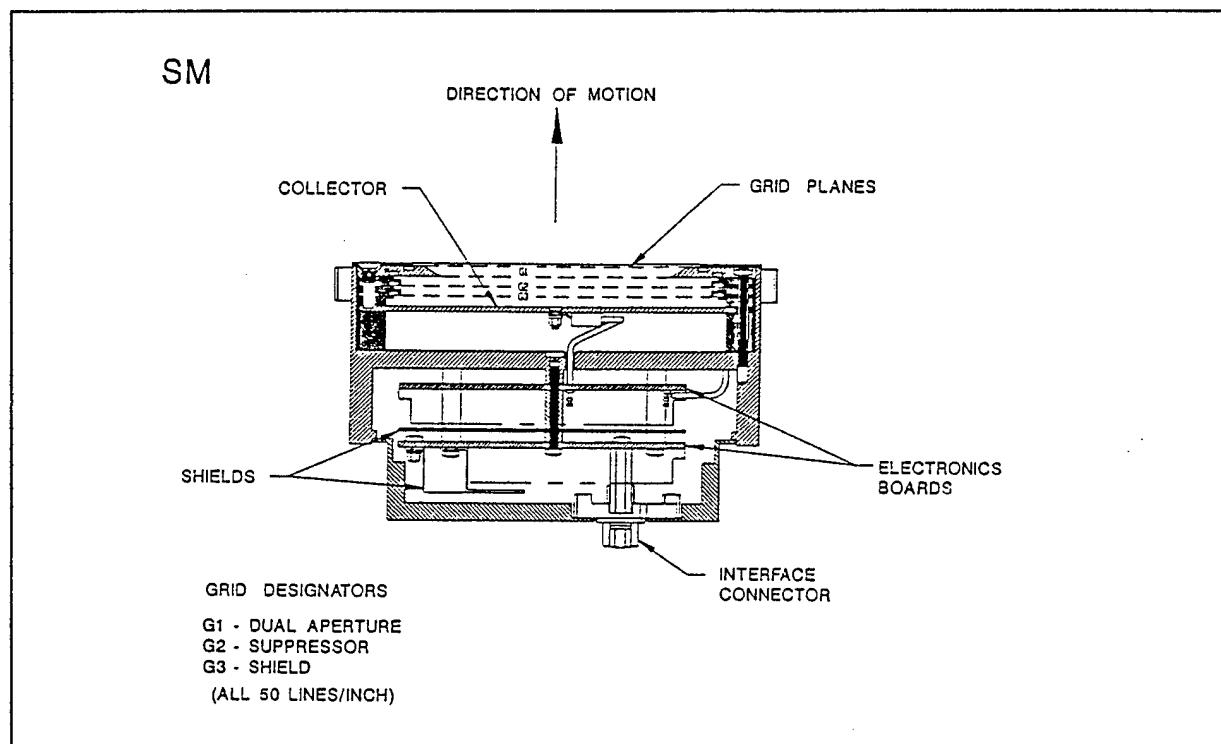


Figure 11. Cross Section of the SSIES3 SM Sensor

4. FUNCTIONAL DESCRIPTION OF THE SENSORS IN THE TOPSIDE IONOSPHERIC PLASMA MONITOR SYSTEM

The purpose of the SSIES, SSIES2 or SSIES3 is to detect and characterize the ambient ionospheric plasma at an altitude of ~840 km from a spacecraft that is travelling at 7.44 km/sec (101 minutes per orbit). The ionosphere at this altitude is composed of O+, H+, and He+ ions, and electrons. At low and mid-latitudes, the ion temperature is ~1000 °K in the nighttime ionosphere and 2500 to 3500 °K in the daytime ionosphere; the electron temperature is 0 to 1000 °K hotter. At 2000 °K, the thermal velocity of O+, H+, He+ and e- are 1.4, 5.7, 2.9 and 240 km/sec respectively. This means that the DMSP spacecraft is moving at a supersonic speed with respect to the ions but at a subsonic speed with respect to the electrons. The thermal energy of the ions and electrons is 0.1 to 0.3 eV. In addition, the speed of the spacecraft gives the ions an apparent energy with respect to the sensors of several eV. All of these factors are important in obtaining a measurement that is not contaminated by effects from the sensors and spacecraft. For example, the solar array has contacts that are exposed to the environment and which may have potentials of up to +28 V (much more than the energy of the ions and electrons). This not only causes a deviation of the normal flow of the plasma around the spacecraft, it also draws electrons into the spacecraft's electric system and drives the spacecraft's ground many volts negative with respect to the ionosphere. The next section describes in more detail some of the problems created by the spacecraft, features of the SSIES, SSIES2 and SSIES3 system designs and the data analysis techniques used to compensate for these problems. This section describes how the sensors work in an ideal environment.

The basic concept of the sensors used in the SSIES, SSIES2 and SSIES3 systems has been used in the investigation of ionized gases (or plasmas) for many decades. The basic design of all the ion sensors is a Faraday cup. Charge carriers flow through an aperture that electrostatically isolates the plasma from the collecting surface. The aperture of a Faraday cup is always planar. The basic design of the electron sensor is a Langmuir probe. Charge carriers are collected by a spherical or cylindrical surface which is directly exposed to the plasma. These classes of sensors are used in many different environments. The sensors described here have been optimized to measure particular parameters of the Earth's ionosphere at altitudes between 300 km and 2000 km.

Electrostatic fields are important to the operation of all of the thermal plasma sensors. In all the ion sensors, the collector plate or surface of the sensor is charged negatively in order to attract positively charged ions. Between the aperture and the collector there are one or more wire mesh screens to help select the ions or electrons that are to be detected and to reject the other particles. The ion sensor apertures are covered with screens set at the same potential as the sensor housing and aperture surface. These screens prevent the internal potentials from leaking out and contaminating the flight of incoming ions. The potential to be felt by incoming particles is set by applying a potential to the wires of the screen. Obviously, the ions must pass through the holes in the screen. Hanson et al.¹² and Spangenberg¹³ and others have shown that the potential within the holes may be slightly different than the potential on the wire. Thus, any screen with a potential that is critical to the measurement has been made a double screen (two screens with the same potential) to minimize this effect. In the electron sensor, a double screen is not used because of the difficulty in manufacturing two perfectly concentric screens.

The basic measurement is the net current being collected by a surface. The sensors screens have potentials applied to try to exclude unwanted current carriers. Besides the thermal ions and electrons, there are several unwanted charge carriers. One unwanted charge carrier is the photoelectron. Photoelectrons are generated by any surface exposed to sunlight. The energy of the photoelectrons is the energy of the UV photon minus the work function of the material or a few eV. By placing above the collector a screen with a potential -15 V or more relative to the collector, most of the photoelectrons will be forced to return to the collector for a zero net current. For the EP sensors, photoelectrons from surfaces other than the collector are collected and measured. Another unwanted charge carrier is the auroral electron. To exclude this carrier, a very large potential barrier would be required. Thus, no effort has been made to suppress the auroral electron. The flux of auroral electrons is insignificant to the flux of thermal particle as long as the ambient density is greater than 10^4 cm^{-3} . At lower densities, an intense auroral flux can contaminate the thermal plasma measurements.

4.1 The Ion Drift Meter (IDM or DM)

The basic concept of how the Ion Drift Meter works is illustrated in Figure 12.

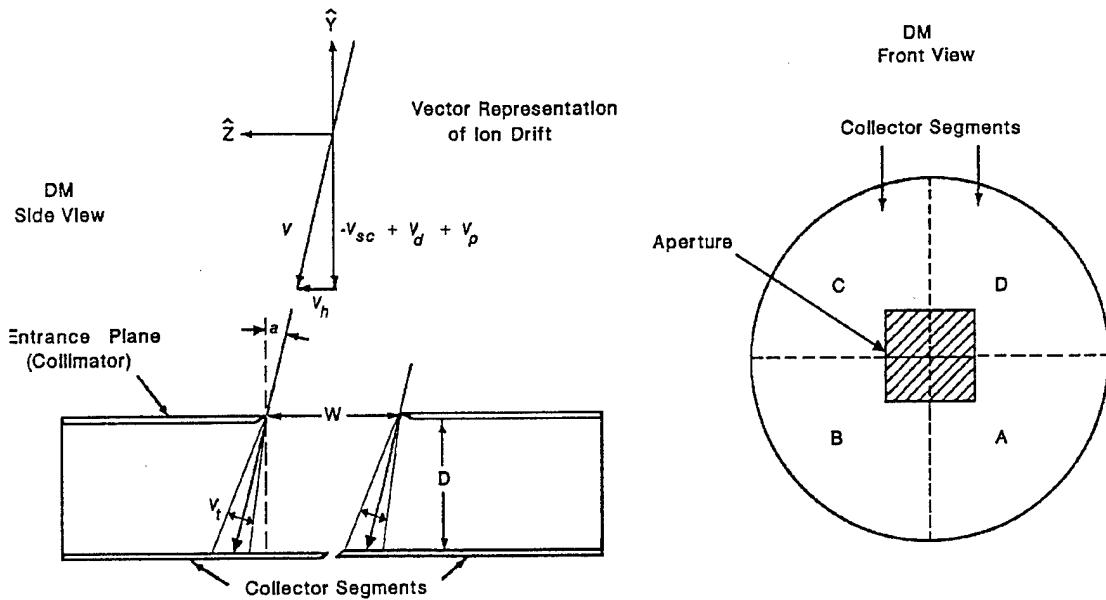


Figure 12. Two Simplified Views of the Drift Meter Collecting Ions

The sensor has a planar aperture which is mounted perpendicular to the spacecraft Y axis $\pm 0.5^\circ$. The spacecraft axes are maintained aligned to the local vertical coordinate system within $\pm 0.01^\circ$. If there is no motion of the plasma in inertial coordinates, then the plasma would have an apparent flow opposite to the spacecraft velocity ($-V_{sc}$) and approximately aligned with the Y axis. In Figure 12, the apparent motion of the plasma due to the spacecraft motion is shown exactly parallel to the Y axis. This is not always true, especially for F10 which is not in a circular orbit. This deviation from the ideal can be handled in the users' data analysis software. In the real world, the plasma is in motion with component in the downrange (V_d), horizontal (V_h) and vertical (V_v) directions. The downrange component adds or subtracts from the apparent spacecraft motion. If there is an electrostatic potential difference between the DM sensor and the ambient plasma, the plasma will acquire an apparent motion (V_p) proportional to the potential drop. Due to measures explained in the next section, this last component is small enough to be ignored. The DM sensor is set up mechanically to measure either the horizontal or vertical component of the plasma motion. If the plasma particles only have motion due to the spacecraft and the bulk flow, then the flow of plasma will cast a distinct spot on the collector of the same size and shape as the aperture. A beam of light projected through the aperture would cast a similar distinct spot on the collector plates. By making the collector of four plates instead of one plate and measuring the difference in current collected, the angle of arrival of the plasma in the horizontal and vertical directions can be determined. The horizontal or vertical components of the plasma motion is then determined as:

$$V_h \text{ or } V_v = (V_{sc} + V_d) \tan a$$

The sharpness of the illumination of the collector plates is degraded by the random thermal motion of the ions (V_t). During the recent maximum of the sunspot cycle, O⁺ ions were the only observable component ~95 percent of the time and are the major component of the plasma ~99 percent of the time. The thermal motion of O⁺ ion is small compared to the spacecraft velocity and does not affect the accuracy of the DM output. When H⁺ and/or He⁺ is the principal component of the plasma, the output of the drift meter may either be very noisy but useful or it may be unusable. To correct for the light ion problem, the DM sensor has an "H⁺" mode. However, this mode has not been used operationally.

4.1.1 Modes of the DM Sensor

The SSIES DM Sensor has two modes of operation: the Normal Mode and the H⁺ Mode. For SSIES2, a third mode (DM FIBA) has been added. The SSIES3 has only the Normal Mode.

4.1.1.1 DM Normal Mode

In normal mode, the drift meter determines the two components of the plasma drift velocity that are perpendicular

to the aperture normal. It does this by measuring the difference in the currents to the top and bottom or left and right halves of its collector plate. The telemetered normal mode data is proportional to the difference between the logarithms of the currents to the halves of the collector plate. The first sample in each second is a measure of the vertical ion flow (positive flow is away from the Earth), the second sample is a measure of the horizontal ion flow. Positive horizontal flow is in the direction toward the spacecraft's -Z axis or nightside for spacecraft with ascending node between 05 and 11 hours and toward the +Z axis or dayside for spacecraft with ascending node between 16 and 23 hours. All other measurements in normal mode continue the cycle between vertical and horizontal measurements.

At times, the plasma may have a substantial H⁺ and/or He⁺ component. These light ions have a thermal velocity comparable to the spacecraft velocity and can make the drift measurement difficult to interpret. To exclude such light ions, the drift meter has a repeller grid that can be biased to a d.c. voltage of 1 V, 1.5 V, 2 V, 2.5 V, or 3 V above the aperture potential. The O⁺ ions, which have a mean energy near 4.6 eV in the spacecraft frame of reference, will pass through the repeller grid, while H⁺ and He⁺, with mean energies near 0.29 eV and 1.2 eV, are excluded. The repeller grid is preceded by a compensation grid which is biased to keep the location and angle of incidence of ions which reach the collector as close as possible to their values in the absence of both grids. A shield grid precedes the collector, and returns ion velocities to their value at the sensor aperture. The suppressor grid electrostatically blocks ambient electrons from reaching the collector and drives photoelectrons from the collector plate back into the plate. On SSIES, the repeller grid has not been used operationally.

4.1.1.2 DM H+ Mode

The goal of the H+ mode is to reject the large drift signal from O+ ions and detect the much smaller drift signal from light ions (H+ and He+). At the DMSP altitude, the ionospheric electric field causes thermal ions of all masses and electrons to convect perpendicularly to the geomagnetic field with a single drift velocity. However, ions may flow upward along the magnetic field lines with mass-dependent velocities. The H+ mode is designed to measure field-aligned flow velocities of light ions. This measurement is difficult to make because the light ions, H⁺ and He⁺, generally make up only a small fraction of the ion population and because the thermal velocities of these ions may be a large fraction of the spacecraft velocity. For these reasons, the light ion current collected by the drift meter is much smaller than the O+ current.

The H+ mode of the DM sensor subtracts the O+ current from total ion current by modulating the light ion signal and synchronously detecting it. The drift meter repeller grid voltage is slowly stepped through a series of retarding voltages. The current to the collector is modulated by a small 200 Hz (100 Hz for DMSP F9) square wave voltage (referred to as a "wiggle") to the retarding grid voltage. The current from each half of the collector plate is input to a synchronous detector. The output of each synchronous detector is proportional to the amplitude of the part of the input signal which shows a 200 Hz modulation. The result is that the DM works like a retarding potential analyzer that measures only the differential current $dI/d\Phi$.

Only the portion of the ion current for which $dI/d\Phi = 0$ is detected. When the d.c. step voltage on the repeller grid is close to the mean energy of the light ions, a large portion of the light ions alternately will be allowed to pass and will be blocked from reaching the collector by the wiggle potential. Since the sum of the step voltages and the a.c. "wiggle" voltages are too small to affect the O+ ions, the O+ current will not be modulated, and will not be detected. The size of the current detected will depend on the value of the d.c. voltage and the wiggle voltage. When the d.c. potential is approximately equal to the mean energy of the light ions, $dI/d\Phi$ will be maximum and the detected current will be maximum. When the wiggle voltage is small compared to $\kappa T_{H^+}/e$, only a small portion of the light ion current will be detected. When the wiggle voltage is large compared to $\kappa T_{H^+}/e$, most of the light ion current will be detected.

Because the light ion species, plasma potential, and the downrange drift velocity are unknown, the light ion mean energy in the spacecraft frame of reference cannot be determined in advance. To insure that the repeller grid voltage is close to the light ion mean energy, the H+ mode employs a 4-second cycle during which both the repeller grid d.c. voltage and the wiggle voltage are varied. During the first and second seconds, data are collected for determination of the vertical light ion drift. During the third and fourth seconds, data are collected for determination of the horizontal light ion drift. As in normal mode, 12 measurements are made each second. An initial DC voltage of 0, 1, 2, or 3 V for the repeller grid is selected by command. For the first two measurements of each second, no wiggle voltage is applied and two normal drift measurements are made, one horizontal and one vertical. For the third through twelfth measurements, the 200 Hz (100 Hz for F9) modulating voltage is added. The repeller grid d.c. voltage is increased by 0.2 V after each measurement from the

third to the twelfth sample. At the end of a second, the modulating voltage is removed, the repeller grid voltage is returned to its original value, and the grid voltage cycle is repeated.

The goal during the first and third seconds of a four second H⁺ mode cycle is to identify the light ion mean energy. During these seconds, a small amplitude is selected for the modulating square wave applied to the repeller grid, so the synchronously detected signal from each half of the collector is proportional to the derivative, $dI/d\Phi$. The signal from one-half of the collector is output to the telemeter. The voltage at which the signal has its maximum identifies the minimum of $dI/d\Phi$ and the light ion mean energy. The first and third seconds of the 4-second H⁺ mode cycle are referred to as the H+DERIV mode.

During the second and fourth seconds of the H⁺ mode cycle, the aim is to measure the light ion drift velocity. A larger modulating voltage is applied to the repeller grid, so that when the grid d.c. voltage equals the mean light ion energy, the signal from each synchronous detector is proportional to the light ion current to the half of the collector plate whose output it measures. During the 10 light ion measurements, the telemetry is proportional to the difference in the logarithms of the modulated signals from the two halves of the collector plate. The exact relationship between the telemetry and the light ion drift velocity cannot be determined before launch. The relationship will be found from flight data by using the fact that the horizontal drift velocity of the light ions is the same as that of O⁺. The second and fourth seconds of the 4 second H⁺ cycle are referred to as the H+DS mode.

Table 4. H⁺ Mode 4-Second Measurement Cycle

Sample No.	Second 1.5.9....	Second 2.6.10....	Second 3.7.11....	Second 4.8.12....
1	H	H	V	V
2	V	V	H	H
3	H+DERIV (V)	H+DS (V)	H+DERIV (H)	H+DS (H)
4	H+DERIV (V)	H+DS (V)	H+DERIV (H)	H+DS (H)
5	H+DERIV (V)	H+DS (V)	H+DERIV (H)	H+DS (H)
6	H+DERIV (V)	H+DS (V)	H+DERIV (H)	H+DS (H)
7	H+DERIV (V)	H+DS (V)	H+DERIV (H)	H+DS (H)
8	H+DERIV (V)	H+DS (V)	H+DERIV (H)	H+DS (H)
9	H+DERIV (V)	H+DS (V)	H+DERIV (H)	H+DS (H)
10	H+DERIV (V)	H+DS (V)	H+DERIV (H)	H+DS (H)
11	H+DERIV (V)	H+DS (V)	H+DERIV (H)	H+DS (H)
12	H+DERIV (V)	H+DS (V)	H+DERIV (H)	H+DS (H)

Table 4 shows the H⁺ mode 4-second cycle, with the 12 measurements made each second. In the table, horizontal measurements are marked with an "H" and vertical measurements with a "V". During the first two measurements of each second, the horizontal and vertical drift velocities of the total plasma are measured as in normal mode. During the final 10 measurements of a second, the repeller voltage is modulated with a 200 Hz (100 Hz for DMSP F9) square wave. There are two choices for modulation amplitudes, WIGLO, and WIGHI. If WIGLO is selected, the modulation is 50 mV for H+DERIV measurements, and 400 mV for H+DS measurements. If WIGHI is chosen, the modulation is 100 mV for H+DERIV measurements, and 800 mV for H+DS measurements. To avoid changes in H+DERIV or H+DS due to changes in the O⁺ arrival angle as the repeller grid voltage changes, the drift meter compensation grid is biased in the opposite sense from the repeller grid, and its bias is modulated 180° out of phase with the repeller grid modulation.

4.1.1.3 DM FIBA Mode

Only the SSIES2 contains a third mode, known as the DM FIBA or Filter Bank Mode. In this mode, the DM output is continuously connected to the normal drift signal as in the NORMAL mode, but the re-zero and offset sequence is changed to accommodate the comb filter bank that is used to extend the bandwidth of the transverse drift velocity measurements. The sequence is shown in Table 5 where V_R and H_R are the vertical and horizontal re-zero measurements respectively. V_O and H_O are the offset measurements and V_D and H_D are "deviation" measurements.

Table 5. DM FIBA Mode 4-Second Measurement Cycle

Sample No.	Second 1.5,9....	Second 2.6.10....	Second 3.7.11....	Second 4.8,12....
1	V_D	H_D	H_D	V_D
2	V_D	H_D	H_D	V_D
3	V_D	H_D	H_D	V_D
4	V_D	H_D	H_D	V_D
5	H_R	H_D	V_R	V_D
6	H_R	H_D	V_R	V_D
7	H_O	H_D		V_D
8	H_O	H_D	V_O	V_D
9	H_D	H_D	V_D	V_D
10	H_D	H_D	V_D	V_D
11	H_D	H_D	V_D	V_D
12	H_D	H_D	V_D	V_D

The re-zero and offset measurements are made as described above for the NORMAL mode. After the last offset reading is taken, the collectors are returned to the re-zero configuration, but the zero switch is left open until the next re-zero sequence. The deviation measurements will therefore reflect any change in collector current ratio from the offset reading. A 30 Hz output filter is used during the re-zero and offset readings and a 6 Hz filter is used during deviation measurements.

To extend the bandwidth of the measurements, the output of the comparison electrometer is AC coupled to a wide band ranging amplifier (WIBAN2) and then to a series of six band pass filters and logarithmic amplifiers. WIBAN2 has five linear sensitivity ranges differing by a factor of 10 for each range change. The WIBAN2 sensitivity range can be automatically determined by the filter channel with the largest output voltage or fixed by ground command. In the automatic ranging mode, WIBAN2 is allowed to range during a window beginning after the 8th sample in odd seconds and ending after the 3rd sample in even seconds. Ranging is disabled at all other times.

The band pass filter frequencies are given in Table 6 where the width of each filter is a factor of 2.4 between the 6 db points. Each filter circuit consists of a logarithmic amplifier preceded by an active band pass filter. Each log amplifier provides an output proportional to the log of the rms of the input signal. The useful dynamic range of each log amplifier is approximately 50 db with a sensitivity of 1.5 volts per decade (nominal). The filters are sampled once every 2 seconds on the MUX (DSM Multiplex, see Appendix) output.

Table 6. DM FIBA Mode Filters

Filter	Bandwidth
FIBA1	12 - 29 Hz
FIBA2	29 - 69 Hz
FIBA3	69 - 166 Hz
FIBA4	166 - 398 Hz
FIBA5	398 - 956 Hz
FIBA6	956 - 2293 Hz

4.2 The Ion Retarding Potential Analyzer (RPA)

Unlike some RPA sensors, care has been taken with the SSIES, SSIES2 and SSIES3 RPA sensors to make the aperture potential as close to the plasma potential as possible and the contours of the potential field in front of the aperture as flat as possible. This allows the use of the assumption that the aperture is part of a semi-infinite surface. The trajectories of ions approaching the aperture are neither bent toward or away from the aperture. Other RPA sensors use a negative "draw-in" potential to enhance the flux of ions. This is useful for extending the sensors sensitivity to a lower density, but in such cases only the ratio of the densities of the ion species can be determined. A sensor with a "draw-in" potential cannot determine the absolute magnitude of the ion density.

The basic equations for analyzing the current to the collector of a planar and spherical retarding potential analyzers were worked out by Langmuir and Mott-Smith¹⁴ and described in detail for a Maxwellian, ionospheric plasma by Smiddy et al.¹⁵. The assumption is made that each specie of the ambient plasma can be described with a single Maxwellian distribution function. That means that only one temperature parameter is needed to describe the plasma. There are cases when the ambient plasma has more than one Maxwellian distribution. Sometimes there is a temperature for the motion parallel and perpendicular to the geomagnetic field. Sometimes, the plasma is a mixture of a low and high temperature plasma. For the data analysis here, such cases will be ignored. This is valid because such cases represent a small fraction of the plasmas being sampled and because the data collection technique is not optimal for such cases.

To calculate the ion current flowing to the collector plates of the RPA sensor, we will assume that the bulk ion flow velocity is normal to the aperture surface. In other words, we will ignore the flow components that are measured by the DM sensor. The electron current is ignored because it is excluded from the collector plate by the potential on the suppressor grid of the RPA. The ion current flowing to a semi-infinite planar surface as a function of the applied potential, ϕ_p , is given below. It is assumed that the aperture potential with respect to the plasma, ϕ , is either less retarding (positive) than the energy of the incoming ions or is slightly accelerating (negative). For $e\phi \leq 0$ (retarding), the current is:

$$I = \frac{A e V_p \alpha}{2} \sum_{i=1}^j \left\{ N_i \left[1 + \operatorname{erf}(x_i) + \frac{\alpha_i \exp(-x_i^2)}{V_p \sqrt{\pi}} \right] \right\}$$

and

$$\frac{\partial I}{\partial \phi_p} = \frac{-A e^2 \alpha}{\sqrt{2\pi\kappa T}} \sum_{i=1}^j \left\{ \frac{N_i}{\sqrt{m_i}} \exp(-x_i^2) \right\}$$

where

$$x_i = \frac{1}{a_i} \left[V_p - \sqrt{\frac{2e\phi}{m_i}} \right]$$

$$erf(x) = \text{ERROR FUNCTION}(x) = \frac{2}{\pi} \int_0^x \exp(-z^2) dz$$

ϕ	= potential of retarding grid with respect to the plasma = $\phi_s + \phi_p$ (volts)
ϕ_s	= potential of the aperture with respect to the plasma (volts)
ϕ_p	= potential of the retarding grid with respect to the aperture (volts)
A	= area of the aperture (m^2) = πr^2 , where r = the aperture radius for a circular aperture
e	= electronic charge of the ions = 1.602×10^{-19} coulomb (assuming singly charged ions)
α	= sensor transparency from aperture to collector
N_i	= ambient ion density of i^{th} specie (m^{-3})
m_i	= mass of i^{th} specie (kg). $m_{H^+} = 1.66 \times 10^{-27}$ kg

$$a_i = \sqrt{\frac{2\kappa T}{m_i}} \quad = \text{mean random speed of ions of the } i^{\text{th}} \text{ specie } (\text{m sec}^{-1})$$

T	= temperature assigned to all ion species (°K)
κ	= Boltzmann constant = 1.38054×10^{-23} joules/°K
j	= number of ion species considered
V_p	= flow speed of the ions = $V_d + V_s$
V_d	= component of the plasma bulk flow velocity parallel to the spacecraft velocity
V_s	= vehicle speed (m/sec) ~ 7446 m/sec for a DMSP spacecraft

When the potential with respect to the ambient plasma on the grids of the RPA sensors is accelerating ($e\phi < 0$), the flux of ions to the collector plate is the same as the flux of ions through the aperture, minus those blocked by the wires of the grids, or

$$I = A e V_s \propto N_i \quad \text{and} \quad \frac{\partial I}{\partial \phi_p} = 0$$

The RPA sensor of the SSIES, SSIES2 or SSIES3 system is made to detect the ion current, I, as a function of the retarding potential, ϕ . It is also possible to make an RPA sensor that detects $\partial I / \partial \phi$ as a function of ϕ . The latter is the basis of the H^+ mode of the DM sensor. It is also possible to construct $\partial I / \partial \phi$ as a function of ϕ by differencing the measurements of $I(\phi)$. In Figure 13, the general shape of both I and $\partial I / \partial \phi$ as a function of ϕ are shown.

A useful fact that can be obtained from the above equation is that when $x_i = 0$, half of the ions of the i^{th} species have been retarded. The potential at which this occurs is also the location of the extrema in $\partial I / \partial \phi$.

In the analysis of the RPA data, the unknowns are T , V_d , ϕ_s , N_i . If there is only one species present, there is not sufficient data to fully determine these parameters. The data will determine the magnitude of $I(x_i = 0)$ which determines N_i and the magnitude of $dI/d\phi(x_i = 0)$ which determines T . The data determines the value of ϕ_p which corresponds to $x_i = 0$, but without more information about V_d , ϕ_s cannot be determined. Since there is only one species, O+, present most of the time, assumptions must be made about V_d and/or ϕ_s .

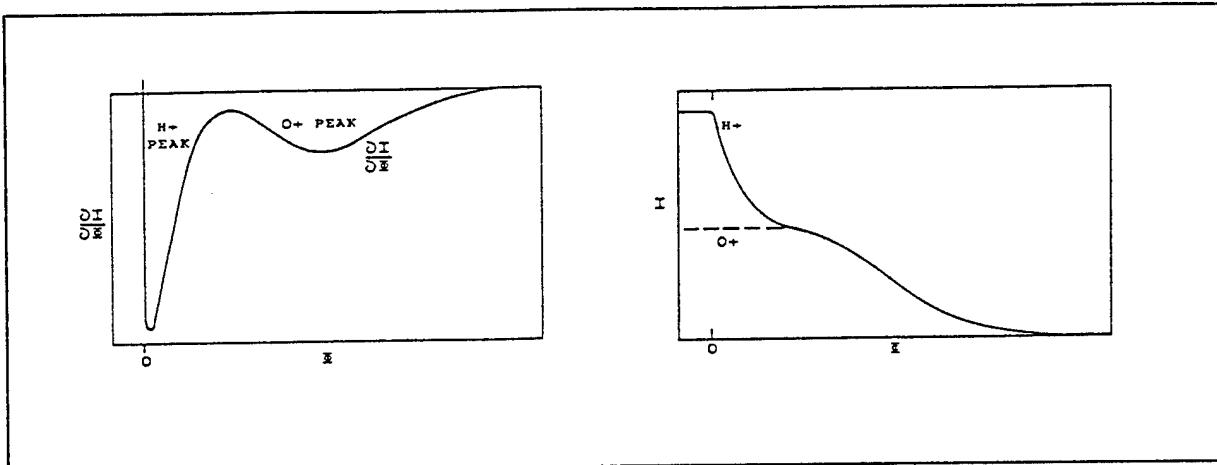


Figure 13. Idealized Functions of the RPA Current Collected and the Differential of the Current

4.3 The Total Ion Trap (SM)

Mechanically, the SM sensor is a very simple Faraday cup or total ion trap. It has a very wide aperture to maximize the ion current to be collected and a minimum number of grids between the aperture and the collector plate. After the ion current reaches the collector plate, it can go through three distinct electronic elements. Those elements are a linear, ranging electrometer, a difference amplifier, and set of band pass filters.

The purpose of the SM sensor is to detect density irregularities (or density fluctuations as a function of distance) of the ambient ionosphere. Because density irregularities at the altitude of maximum ionospheric density (h_{F2}) are known to cause scintillations of radio signals passing through, the SM sensors are sometimes referred to as the "Scintillation Meter." If the SM sensor detects significant density variations at the DMSP altitude, there is always a scintillation-causing density variation at h_{F2} below the satellite. Detection of such areas is the prime use of the SM data. The SM data are limited by the fact that scintillation-causing density variations can occur at h_{F2} below the satellite without a similar density variation being present at the DMSP altitude.

The current from the SM collector plate goes to a ranging, linear electrometer. If the ionospheric density varies by a significant amount over the span of a few seconds, the output of the ranging, linear electrometer will be digitized and placed in the telemetry stream 24 times per second. If the ionospheric density does not vary significantly, the output of the electrometer is stored at one terminal of a $\times 10$ difference amplifier. Then the output of the difference electrometer is output 24 times per second. With this scheme of measurements, the smallest scale size of irregularity detectable is 620 meters ($=7.44 \text{ km/sec}$ divided by the Nyquist frequency of the measurements). To expand the SM range to smaller scale sizes, the analog output of the linear electrometer is attached to a wide band amplifier which is in turn attached to a set of band pass filters. For SSIES, there are 9 filters. For SSIES2 and SSIES3, there are 6 filters. The frequency range of the filters is given in Table 7. Each filter provides an output proportional to the log of the rms of the input signal. The filters are sampled once per second.

Table 7. SM Band Pass Filter Frequencies

Filter No.	Band Pass Freq. / SSIES	Band Pass Freq. / SSIES2/SSIES3
1	12 - 26 Hz	12 - 29 Hz
2	26 - 56 Hz	29 - 69 Hz
3	56 - 120 Hz	69 - 166 Hz
4	120 - 260 Hz	166 - 398 Hz
5	260 - 560 Hz	398 - 956 Hz
6	560 - 1200 Hz	956 - 2293 Hz
7	1.2 - 2.6 Hz	n/a
8	2.6 - 5.6 Hz	n/a
9	5.6 - 12 Hz	n/a

In order to save telemetry, there is not a separate word for the SM electrometer range indicator for each SM data value, and the indicator for whether the electrometer or difference amplifier output is being sent to the telemetry is not available as a separate data word. These indicators are mixed into the 24 SM data outputs as needed. The SM electrometer and wide band range are sampled once a second for SSIES and every even second for SSIES2. When the SM electronics changes its state, one or two samples of the SM data are over-written with a value that indicates the change of state. The values of these "change of state" data have been selected to be clearly different from the ion density data values. The SM electrometer range indicator is output as a separate word once each second (SSIES) or every other second (SSIES2). Since the range can change more often than that, the 24 samples per second must be examined to determine the state of the electronics. This results in the loss of several seconds of usable SM data after each gap in the telemetry.

In a quiet ionosphere, the SM electronics uses a 16-second cycle. (Actually, the cycle may be only 15 seconds long because the SM is synchronized to eight odd values of the system counter which is in word 1 of the telemetry.) If the SM is in the electrometer mode just before the beginning of a cycle, the "electrometer-to-difference-amplifier-mode" flag will be placed in the first sample of the first second of the cycle. The following SM data values will be sent from the difference amplifier until either the difference amplifier goes out of its limits or 16 seconds has elapsed. When the difference amplifier goes out of its limits, the "amplifier-to-electrometer" flag is set into the data for one or two samples and then the output from the electrometer is put into the telemetry. If the difference amplifier goes out of its limits within 1 second of starting, electrometer data is sent for the remainder of the 16-second cycle. If the difference amplifier goes out of its limits after sending data for 1 second, the "amplifier-to-electrometer" flag is set and electrometer data goes to the output until the next odd count of the system counter. At that point, the "electrometer-to-difference-amplifier-mode" flag is sent for one sample and a new 16 second cycle begins. If the difference amplifier sends data to the output for 16 seconds, the next cycle begins with one or two samples of the "amplifier-to-electrometer" flag, two or three samples of the electrometer data and then the "electrometer-to-difference-amplifier-mode" flag appears as the 5th sample.

In a noisy ionosphere, the SM electronics will always be in the electrometer output mode and the range will change several times a second. In fact, there is a possibility that only "range change" flags and no data will appear in the SM output. This is especially true of the SSIES instruments which did not have an adequate overlap in the set points for the range changes.

The control flags that appear in the SM output are given in Table 8. The "difference-amplifier-to-electrometer-mode" flag was designed to be zero (0) counts, but a mistake in the engineering has caused it to be different than zero. For SSIES, the number of counts used for this flag is approximately half the ion sensor array aperture voltage. The overlap of this flag with the electrometer range change flags can cause some incorrect interpretation of the data. For SSIES2, it is not known at this time why the flag is not at zero counts.

Table 8. SM Control Flags

Event	Flag / SSIES	Flag / SSIES2	Flag / SSIES3
Difference Amplifier to Electrometer Output with No Change in Electrometer Range	0 - 14	0 - 9	0 ?
Electrometer Range Change (and Diff. Amp. to Elect. Output If Necessary): To Range 1 (6.32×10^{-9} Amp / TM Volt)	28 - 31	26 - 27	?
To Range 2 (2.0×10^{-8} Amp / TM Volt)	24 - 27	22 - 23	?
To Range 3 (6.32×10^{-8} Amp / TM Volt)	19 - 21	19 - 21	?
To Range 4 (2.0×10^{-8} Amp / TM Volt)	16 - 17	16 - 17	?
To Range 5 (6.32×10^{-7} Amp / TM Volt)	12 - 14	12 - 13	?
Electrometer to Diff. Amplifier Output	511	511	511

The upper and lower bounds at which the electrometer changes ranges have been set so that the above control flag values are outside the normal data range. If the instrument encounters densities less than 700 cm^{-3} , the electrometer will be in Range 1 and telemetered data will have values less than 34. This may cause confusion with control flags unless the density from past samples is tracked. Densities much above 10^6 will cause the SM electrometer to saturate in range 5. In this case, the telemetry will show a steady stream of 511's, since this is the highest number possible to telemeter. Since the 511 control flag can appear only in the first or fifth telemetry reading of a second, saturation should be easy to distinguish.

It has been found that occasionally the "Diff-to-Electrometer" flag appears in the 24th sample of an even count on the system counter. When this happens, the electrometer sample(s) which should appear in the next sample may be missing. The next sample in the telemetry is a 511 flag. At this point, the user has no way to determine the electrometer values stored at the difference amplifier. In this case, the data cannot be interpreted until the next "Diff-to-Electrometer" flag appears in the data.

4.4 The Spherical Langmuir Probe for Electrons (ELEC or EP)

The spherical Langmuir probe used in the SSIES/SSIES2/SSIES3 system has been modified from the standard Langmuir probe design. In the standard design, a spherical or cylindrical conducting surface is directly exposed to the plasma and collects both ions and electrons as the potential on the probe is varied. In this design, the spherical collector is behind a spherical grid that electrostatically blocks ambient ions from reaching the collector. There is a positive potential on the collector with respect to the spherical grid to insure that any electron passing through the spacings in the grid will be drawn to the collector and thermal ions will be ejected before reaching the collector. This simplifies the analysis of the data since only one species, electrons, needs to be considered. There is one complication to this design; photoelectrons ejected from the wires of the grid will be collected. As long as the flux of ambient electrons exceeds the flux of photoelectron, this is not a significant problem. The collector radius is only slightly less than the gridded sphere radius to minimize the amount of grid material exposed to sunlight. Photoelectrons from the body of the spacecraft are reduced by placing the probe at the end of a boom that is several Debye lengths (or scale heights) in length.

There is an electrostatic sheath around the electron probe with a thickness of approximately 3 Debye lengths (Debye length = $6.91 (T_e / n_e)^{1/2} \text{ cm}$, where $T_e = 1000 - 4000 \text{ }^{\circ}\text{K}$ and $n_e = 10^3 - 10^6 \text{ cm}^{-3}$ for the DMSP orbit). At the outer edge of the sheath, the electric potential created by the spherical sensor is suppressed and the plasma is in its ambient state. Within the sheath, the density of accelerated species is depleted. Also within the sheath, the trajectories of accelerated species are bent toward the probe and the trajectories of retarded species are bent away from the probe. For the DMSP probe, the sheath thickness is greater than the dimensions of the probe. As the grid potential goes more positive with respect to the plasma potential, more electrons are drawn into the probe than would reach the probe due to normal random motion. When the probe is retarding electrons, the disturbance to the ion distribution is unimportant because they are supersonic and

because they are not being collected.

The electron current, I_e , to a gridded spherical sensor is a function of the sensor's grid potential, ϕ , with respect to the plasma. If ϕ is positive, then electrons are accelerated to the sensor. If ϕ is negative, they are retarded as they approach the sensor's grid. If it is assumed that the electrons can be described by a single Maxwellian distribution function, then the relationship of current collected can be derived. For a retarding potential, $\phi < 0$, we have:

$$I_e = A e \alpha N_e a \frac{\exp(-x^2)}{2 \sqrt{\pi}}$$

and

$$\partial I_e / \partial \phi_p = -A e^2 \alpha N_e a \exp(-x^2) / (2 \kappa T_e \sqrt{\pi})$$

For an accelerating potential, $\phi > 0$, then:

$$I_e = A e \alpha N_e a (1 - x^2) / (2 \sqrt{\pi})$$

and

$$\partial I_e / \partial \phi_p = -A e^2 \alpha N_e a / (2 \kappa T_e \sqrt{\pi})$$

where

x^2	$= a^2 (2 \phi / m_e)$
ϕ	= potential of the sensor grid with respect to the plasma $= \phi_s + \phi_p$ (volts)
ϕ_s	= potential of the sensor grid with respect to the plasma (volts)
ϕ_p	= potential of the sensor grid with respect to the SSIES reference potential (volts)
A	= area of the gridded sphere (m^2) $= 4 \pi r^2$, where r = the gridded sphere radius
e	= electronic charge of an electron $= -1.602 \times 10^{-19}$ coulomb
α	= transparency of the gridded sphere
N_e	= ambient electron density (m^{-3})
m_e	= mass of electron $= 9.1085 \times 10^{-31}$ kg
a	= mean random speed of electrons (m / sec) $= (2 \kappa T_e / m_e)^{1/2}$
T_e	= electron Temperature ($^{\circ}K$)
κ	= Boltzmann constant $= 1.38054 \times 10^{-23}$ joules/ $^{\circ}K$

In analyzing the data from the spherical electron probe, it should be noted that there is a linear relationship between $\log_{10}(-I_e)$ and ϕ_p . We obtain:

$$\partial \log_{10}(-I_e) / \partial \phi_p = e / (\kappa T_e \log_e(10))$$

and

$$T_e = \frac{5040 \text{ } ^\circ\text{K}}{S}$$

where S is the slope of $\log_{10}(-I_e)$ versus ϕ_p .

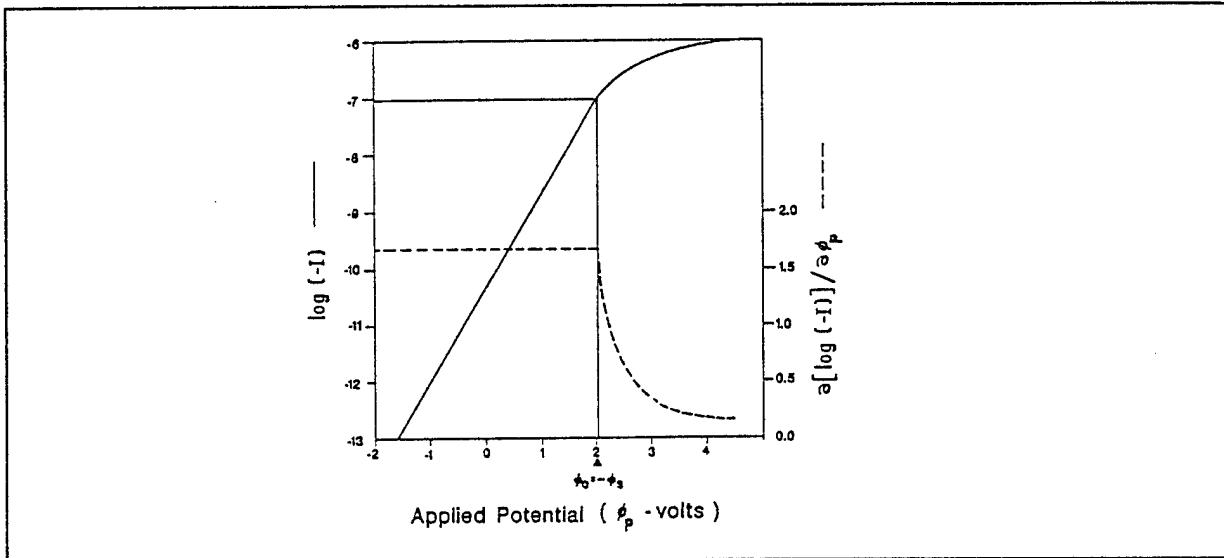


Figure 14. Idealized Functions of the \log_{10} of the EP Current Collected and Its Differential

An idealized curve of output of a log electrometer versus the voltage applied to the grid of the Langmuir probe is shown in Figure 14. The idealized curve shows only one population of electrons. In sunlight, there is a second population of photoelectrons with $T_e \approx 25.000 \text{ } ^\circ\text{K}$ and $N_e \approx 1 \text{ to } 10 \text{ cm}^{-3}$. When the spacecraft is in darkness and the ionosphere in the opposite hemisphere and on the same geomagnetic field line is in sunlight, there may be a second population of electrons observed ($N_e < 100 \text{ cm}^{-3}$) that have escaped from the opposite hemisphere. Another feature of the idealized curve is the implicit assumption that in the acceleration region, the spacecraft potential ϕ_s does not change. In fact, the accumulation of electrons by the probe in the acceleration region of the sweep cycle does tend to drive the spacecraft potential negative.

4.4.1 EP Modes of Operation

There are four different cycles that the potential on the EP sensor can have. The cycles are large sweep, normal sweep, short sweep, or dwell. Each of the EP modes of operation is one set of these cycles. The EP mode is selected either as the default mode from the power-up sequence or by a command received from the ground.

The large sweep cycle was designed for SSIES to assist the system in determining the potential between the plasma and the spacecraft from the EP data. After SSIES was designed, the SENPOT system was designed as an alternative method of determining the potential and was retrofitted onto the last two SSIES units. The large sweep cycle causes the potential on the EP grid to cover the full range of voltages within the capability of the SSIES system in 8 seconds. The large sweep cycle consists of two 4-second cycles: a 3-second sweep from -6 V to +14 V with respect to V_{BIAS} followed by 1 second with a constant voltage on the EP grid of 0 V with respect to V_{BIAS} . During the first sweep, $V_{BIAS} = +2 \text{ V}$ with respect to the spacecraft ground. During the second sweep, $V_{BIAS} = +17 \text{ V}$ with respect to the spacecraft ground. (See Section 5.2 for more information on the methods of setting the SSIES potential V_{BIAS} .) Because the large sweep can disturb the measurement of the ion sensors, a flag bit is set in the Cycle ID word during the 8 seconds that this mode is in operation. At all other times, V_{BIAS} is set to a value determined by SENPOT, the microprocessor or ground command.

The normal sweep cycle consists of two 4-second sweeps. The potential on the EP grid is swept from -4 V to +4 V with respect to V_{BIAS} in 4 seconds and then from +4 V to -4 V in the next 4 seconds. This is the cycle most often used by the EP sensor. The EP sensor may collect excess electrons when the sweep is at +4 V and make a small change in the

potential of the spacecraft with respect to the plasma. In most cases, the change is too small to disturb the data collection of the ion sensors.

The short sweep cycle consists of the same sequence of voltages as the normal sweep except that the speed of the sweeps is doubled. The potential on the EP grid is swept from -4 V to +4 V with respect to V_{BIAS} in 2 seconds and then from +4 V to -4 V in the next 2 seconds. This mode was designed to assist in data collection when the environment is rapidly changing in regions like the auroral zones. This mode has not been used operationally for SSIES or SSIES2.

The dwell cycle is simply a period of a fixed voltage of V_{BIAS} being placed on the EP sensor grid. During the dwell cycle, analysis of the collected electron current gives small scale changes in the plasma density but cannot give the electron temperature. This cycle is designed as a backup for the SM's determination of plasma irregularities.

4.4.1.1 EP Modes for SSIES

For SSIES, there are 5 operating modes, which are labelled A, B, C, D, and E. The sequence of cycles in modes A and B and the sequence in modes C and D are identical. The difference is that in modes A and C, the V_{BIAS} level is set by the microprocessor after it analyzes the EP data. In modes B and D, the V_{BIAS} level is set either by a ground command or by the SENPOT circuit. Mode A is the power up default mode for SSIES.

In modes A and B, the EP grids have a large sweep cycle applied to them during the first 8 seconds of a 128-second period. During the next 120 seconds, a series of normal sweep cycles is applied. In mode A, the microprocessor can replace any regular sweep with a large sweep if the spacecraft potential changes faster than it can keep up with by analyzing normal sweep data.

In modes C and D, the EP grids have a large sweep cycle applied to them during the first 8 seconds of a 1024-second period. During the next 1016 seconds, there is a series of 32-second cycles consisting of a 4-second sweep from -4 V to +4 V and 28 seconds of a dwell cycle.

In mode E, the EP grids have a large sweep cycle applied to them during the first 8 seconds of a 128-second period. During the next 120 seconds, a series of short sweep cycles is applied.

4.4.1.2 EP Modes for SSIES2

For SSIES2, there are 7 operating modes, which are labelled A, B, BS, C, D, DS, and E. These modes are almost identical to the SSIES modes. The difference is that in modes B and D the V_{BIAS} level can only be set by ground command. In modes BS and DS, the V_{BIAS} level can only be set by the SENPOT circuit. Also, when the BS or DS mode is commanded, the SENPOT system is activated without any further commands.

4.4.1.3 EP Modes for SSIES3

The SSIES3 has only one operating mode for the EP sensor. This mode is a modified form of the E mode. There are no large sweep cycles; only short sweep cycles. Also, the range of the short sweeps has been changed from a fixed range of -4 V to +4 V to range of -6 V to +2 V with a commandable offset in the range of -6 V to +2 V.

4.5 Timing

In SSIES, most of the data words are collected from the analog-to-digital converter just before they are placed in the telemetry buffer and they are placed in the telemetry buffer in the order in which they are sampled. By using Table 10.1.1, one can determine the timing of the SSIES data samples within a 1-second frame. The SM and DM data are collected at almost uniformly spaced points in time. The RPA output is internally sampled 149 times per second. The microprocessor uses all data points for its analysis of the data and creates 25 averaged values of the RPA data. The first 24 average values are placed in the telemetry buffer and the 25th value is dropped. To obtain a proper timing of RPA values, the dropped sample must be accounted for. The EP output is internally sampled 25 times per second. Like the RPA data, the 25th sample is dropped. To get the EP proper timing, the dropped sample must be accounted for. In SSIES2, the same system of internal data sampling is followed but the values are not placed in the output buffer in the same sequence in which

they are sampled. By comparing the values in Table B1 and B2 with the corresponding values in Table A1, one can determine the timing of the SSIES2 data samples with a 1-second frame. For SSIES3, the RPA and EP data sampling has been modified so that there are no dropped samples. To a reasonable approximation, the samples from the RPA, EP, DM and SM are uniformly sampled during the 1-second frame.

The microprocessor analyzes data from the RPA and EP sensors and puts the results into the output buffer. Since the microprocessor must accumulate a full sweep cycle of data before beginning its processing, the outputs in the telemetry from the processing are delayed from the beginning of the sweep by at least the length of the sweep. The EP data are analyzed during the first second following the sweep, and the ion RPA data during the second second. The telemetered values for the plasma parameters are updated at different times during the 4-seconds after the sweep data from which they are calculated appears in the telemetry. Except for electron data from the 3-second large Langmuir probe sweeps, the timing of updates is as follows:

- Second 1: Electron temperature, spacecraft potential derived from electron data, and electron computation monitor.
- Second 2: Electron, H⁺, and O⁺ density, downrange drift velocity and spacecraft potential computed from the ion data.
- Second 3: H⁺ and O⁺ temperature. During Mode E only, electron temperature, spacecraft potential derived from electron data, and electron computation monitor from raw data telemetered during seconds 1 and 2.
- Second 4: During Mode E only, electron density from raw data telemetered during seconds 1 and 2.

When a large 3-second Langmuir probe sweep occurs, the microprocessor-computed electron density is telemetered in the first second after the sweep data has been telemetered (with data from second 4 or 8 of the large sweep sequence) and the electron temperature, spacecraft potential, and electron computation monitor in the second (with data from second 5 of the large sweep sequence or the first second after the sequence.)

SSIES data collected during one second are sent to the OLS system for placement in the telemetry at the beginning of the SSIES's next second of operation. When the OLS begins reading out data from the SSIES and other mission sensors, it generates a time tag with a least significant bit of 1/1024th second. It is common practice to associate the first sample in a telemetry frame with the time tag in the telemetry frame, but that IS NOT CORRECT! The sample was acquired approximately one second before the time tag. This is also true of the SSM and SSJ4 data. For the SSUSI, there is a 4-second lag between the time of the data collection and the time it is placed and time tagged in the OLS output buffer. If the application using the time tag is comparing SSIES data with SSJ4 and/or SSM data analyzed in the same manner, then this error is unimportant. If the application is comparing the SSIES data with some other data source, this 1-second error may be important.

The period of time during which the OLS is moving bits out of the mission sensor's output buffer is called the "read-gate." For SSIES and SSIES2, bits are transmitted from the mission sensors to the OLS at 9990.24 bits/s. For SSIES3, bits are transmitted to the OLS at 25.6 kHz +/- 1 Hz. The read-gate occurs once a second ± 2 ms. The ± 2 ms of jitter is included in the OLS time tag. The difference between the beginning of a mission sensor's read-gate and the time tag depends upon the number of words allocated to other DMSP mission sensors that are read out ahead of the given mission sensor. Tables 9 - 13 show the read out order and the delay of a mission sensors read gate from the OLS time tag. This information is based upon the best information available to this writer. The OLS system can be re-programmed at any time. For the best possible information, a user must use the information in the OLS telemetry, which is not included in the SSIES raw data files, or ask the personnel at the spacecraft operations center.

The OLS time tag is synchronized with Greenwich Mean Time within a few ms. The OLS clock is reset each day. It is possible that the clock will register times greater than 86400 seconds if the reset does not occur exactly at midnight. There is no day counter in the telemetry; thus, the data is correlated with the proper day of the year after the data reaches the ground.

Table 9. F8 Sensor Read-Out Order and Timing

Mission Sensor	No. of 36 Bit Words	Delay of Read Out from OLS Time Tag (sec)
SSIES	30	0.0000
SSMT-1	4	0.1081
SSJ4	10	0.1225
SSBX	5	0.1586
SSMI	91	0.1766

Table 10. F9 Sensor Read-Out Order and Timing

Mission Sensor	No. of 36 Bit Words	Delay of Read Out from OLS Time Tag (sec)
SSBX	5	0.0000
SSIES	30	0.0180
SSJ4	10	0.1261
SSMT1	4	0.1622
SSK	5	0.1766

Table 11. F10 Sensor Read-Out Order and Timing

Mission Sensor	No. of 36 Bit Words	Delay of Read Out from OLS Time Tag (sec)
SSIES	30	0.0000
SSMT1	4	0.1081
SSJ4	10	0.1225
SSMI	91	0.1586
SSBX	5	0.1766

Table 12. F11(S12) Sensor Read-Out Order and Timing

Sensor	No. of 36 Bit Words	Delay of Read Out from OLS Time Tag (sec)
SSIES2	20	0
SSJ4	10	0.0757
SSMT1	4	0.1117
SSMT2	9	0.1261
SSMI	91	0.1586
SSBX2	5	0.4865

Table 13. F12(S11) Reading-Out Order and Timing

Sensor	No. of 36 Bit Words	Delay of Read Out from OLS Time Tag (sec)
SSIES2	20	0
SSJ4	10	0.0721
SSBX-2	5	0.1081
SSMT-1	4	0.1261
SSMT-2	9	0.1405
SSMI	91	0.173
SSM	7	0.5009

5. INTERACTIONS BETWEEN THE PLASMA SENSORS, THE SPACECRAFT AND THE ENVIRONMENT

A body composed of conducting material at rest in a plasma will acquire a negative potential ($\approx -3 \times \kappa T_e / e$) with respect to the plasma due to the higher speed of thermal electrons than of thermal ions. This is often referred to as the "floating potential." For a body moving supersonically with respect to the ions, the flux of ions is enhanced on the front surface and depleted on the rear surface. For a conducting body, this has little effect on the acquired potential. For a non-conducting body, the high speed flow of ions makes the potential on forward surface slightly less negative than the floating potential. The potential on the rear surfaces is slightly more negative. If the body is in sunlight, photoelectrons will be ejected causing a negative current to flow away from the spacecraft which is equivalent to a positive current to the sunlit surfaces. If the body is in the auroral zone, the top surfaces will collect negative current from the auroral electrons flowing down the geomagnetic field lines. If one element of a body is positively charged with respect to the plasma, it will draw in a negative current. This draw-in current will tend to push the potential of that element of the body toward the floating potential.

The exposed surfaces of the DMSP spacecraft are mostly non-conducting material. Forward surfaces are near the floating potential (-0.5 V to -2.0 V) and rear surfaces have slightly more negative potentials. In regions of extremely intense auroral electron flux with low thermal plasma density and no sunlight, surfaces on DMSP can acquire potentials as negative as -400 V¹⁶. The ground potential of the spacecraft's electronics is determined by the potential of the small amount of surface that is conducting.

Most of the conducting surface of the DMSP spacecraft is found in the connectors and shunts of the solar array and in the surfaces of the SSIES sensors and ion array mounting plane. When the spacecraft is in sunlight, some of the contacts of the solar array are biased positive with respect to the electrical ground of the spacecraft. This draws in electrons and makes the spacecraft -10 to -28 V with respect to the plasma. When the spacecraft is in the Earth's shadow, the solar panels do not generate any potential and the spacecraft's ground changes to the floating potential (-2 V to -0.5 V) over several minutes. When the spacecraft enters sunlight from the Earth's shadow, the potential changes over a period of a second or two to the potential created by the solar panels. The rapid change to a more negative potential is due to the high mobility of electrons. When the spacecraft enters the Earth's shadow from sunlight, the spacecraft potential becomes less negative over a period of tens of seconds as the almost immobile ions are collected to cancel the excess negative charge.

Most of the exposed conducting surfaces of the SSIES system are electrostatically passive. During part of the EP's 4-second sweep cycle, the grids of the EP sensor develop a positive potential with respect to the plasma, especially during the large or "bias-setting" sweeps. The positive potential on the EP sensor can drive the spacecraft's ground a few volts negative. The effect of a positive EP potential is strongly dependent on the ambient plasma density, the sunlight conditions on the EP sensor and the spacecraft, and other factors. In general, the large sweep does disturb the SSIES ion measurements but a normal sweep does not.

5.1 Electrostatically Biasing the SSIES Sensors

It is critical that the electrostatic potential of the ion sensors aperture and the ground level of the EP sensor sweep be no more than 1 V more negative than the floating potential. To ensure this, the ion sensors are referenced to a floating potential called $V_{APERTURE}$ and the EP sensor is referenced to a floating potential called V_{BIAS} . These potentials are generated within the SSIES, SSIES2 and SSIES3 electronics. These two potentials are related to each other as $V_{APERTURE} = V_{BIAS} + V_{IP}$, where V_{IP} is set by command to 0, -1, -2, or -3 V. In general, V_{IP} is set to -1 V. This tends to keep both the ion array and the reference level for the EP sweep close to the floating potential.

The $V_{APERTURE}$ or V_{BIAS} level is set by one of three procedures. First, there are commands available that will set V_{BIAS} to a fixed level. These levels are spaced 1 V apart. Second, the microprocessor can analyze the data from the EP, especially from the large or bias-setting sweeps, and determine the proper level for V_{BIAS} within approximately 1 V and step it in increments of 1 V. In this mode, the V_{BIAS} level can change only every 4 seconds. Third, a special potential detecting and bias setting system known as SENPOT can set the potential. The concept of SENPOT is described by Zuccaro and Holt. In this mode, the V_{BIAS} level changes continuously and in increments of any size within its range. The first two modes were conceived in the design phase of SSIES. The third mode was conceived after the SSIES was designed and was retrofitted onto the second and third SSIES units. The first SSIES unit, flown on F9, does not contain a SENPOT system. When

the EP sensor on F9 worked, the microprocessor controlled the V_{BIAS} level. After the F9 EP sensor stopped working, the V_{BIAS} level was set by a series of stored commands. For F8, F10 and all future units, the SENPOT mode has proven to be the preferred method of setting the V_{BIAS} level.

5.2 The SENPOT Mode

SENPOT is an analog system that keeps $V_{APERTURE}$, the reference potential of the ion sensors, close to the plasma potential. One section of the ion sensor aperture plane is electrically isolated from the rest of the SSIES system by $100\text{ M}\Omega$. This surface should be at the plasma floating potential. The voltage difference between this reference surface and the spacecraft's electrical ground is detected. The signal from the voltage detection is used to drive an amplifier that controls $V_{APERTURE} = V_{SENPOT} + V_{BIAS} + V_{IP}$. As described above, V_{IP} is set by command. V_{BIAS} goes to a pre-determined value when the SENPOT mode is selected. For the SSIES, $V_{BIAS} = +13\text{ V}$ in SENPOT mode, and for the SSIES2, $V_{BIAS} = +7$ or $+21\text{ V}$. The SSIES2 SENPOT circuit automatically switches the V_{BIAS} level, as necessary. The range of V_{SENPOT} is $\pm 13\text{ V}$ for SSIES and is $\pm 12\text{ V}$ for SSIES2. In the SENPOT mode, the reference voltage of the EP sensor is $V_{APERTURE} - V_{IP} = V_{SENPOT} + V_{BIAS}$.

For SENPOT to function properly, the plasma current to the SENPOT reference surface must exceed the leakage current and the photoelectron current. Calculations indicate that this condition will be met as long as the plasma density is greater than 10^3 cm^{-3} . Experience with the system on F8, F10 and F11 indicates that SENPOT works well at densities as low as $2 \times 10^2\text{ cm}^{-3}$. At this level, there are problems with the ion measurements which may or may not be related to SENPOT.

6. DATA ANALYSIS METHODS

The first step in analyzing data from the SSIES, SSIES2 or SSIES3 is to separate the data words in the telemetry. As described in the Data Archiving section, there are several possible formats in which the user might receive raw data. After obtaining a 1 second block of data, the user needs to separate each 9-bit data word as described in the appendices. Each 1 second block of data contains raw data from each of the 4 sensors (either the EP or RPA raw data may be missing from the SSIES2 data block), control words describing the state of the instrument and words containing the results of RPA and EP data analysis done by the on-board microprocessor. All of the raw data can be considered as counts from 0 to 511 or as voltages from 0.00 to 5.11 volts. The following is a description of how to convert the SSIES, SSIES2 or SSIES3 raw values into geophysical parameters.

6.1 The Ion Drift Meter (IDM)

Since almost all of the data is collected while the DM sensor is in normal mode, the normal mode is the only mode described in this section. In normal mode, 12 drift meter measurements are made every second, 6 vertical and 6 horizontal. To a reasonable approximation, the samples are uniformly spaced in time and a Fourier analysis of the flight measurement can be performed. The process of obtaining plasma drift values from the SSIES, SSIES2 or SSIES3 raw data is very simple:

$$V_{H \text{ or } V} = (V_s + V_D) \times (0.01 \times \text{Counts} - V_{\text{zero}}) \times C_D$$

where

V_s	=	spacecraft speed (or component of spacecraft velocity parallel to aperture normal if the aperture is mis-aligned with the forward direction.) (m/sec)
V_D	=	component of the plasma drift in the down-range direction (set equal to zero for most processing) (m/sec)
V_{zero}	=	Re-Zero Voltage \approx 2.56 V (See comment below)
C_D	=	Calibration Constant \approx 0.1413 / V (See comment below)

The drift re-zero value, V_{zero} , is calibrated prior to launch. However initial post-flight analysis of the F8 - F10 data found an apparent variation by a few counts from day to day and from season to season in the range of 2.56 ± 0.04 V. This gives an uncertainty in the absolute velocity measurement of ± 42 m/sec. For the analysis of the cross-polar-cap potential, a re-calibrate is done each orbit by setting the drift speeds to zero at mid-latitude after removing the co-rotation drifts. A recent re-examination of the mid-latitude drift data has shown that this apparent change in calibration is actually a variation in the mid-latitude ion drift velocity which was originally and erroneously assumed to be zero.

The calibration constants, C_D , for F8 through F11 are 0.1463, 0.1413, 0.1438 and 0.1621 respectively. The preliminary value for S11 through S15 is 0.1621, but that might change after a review of in-flight data. The values for S16 through S20 will be approximately 0.21.

The measured drifts are with respect to inertial space. If there are no other forces working on the ionospheric plasma, the plasma is drifting from west to east at the same speed as would if it were attached to the surface of the Earth beneath the spacecraft. This is known as co-rotation. Since the user usually wants to obtain the drifts due to other factors, the user should remove the co-rotation drift from the horizontal component.

6.2 The Ion Retarding Potential Analyzer (RPA)

The RPA data is processed to find the density of H⁺ and/or He⁺, and O⁺, the ion temperature, the downrange component of the plasma drift velocity, and the RPA aperture potential with respect to the ambient plasma. Although it is possible for the temperature of the light ions to be different from the O⁺ temperature, we assume that the temperatures of all the ion species are the same. Much of the time O⁺ is the only ion species detectable. If a light ion species is present in a detectable quantity, it is very difficult to determine the ratio of H⁺ to He⁺. The energy acquired by H⁺ and He⁺ from the spacecraft ram velocity is similar and is of the same order of magnitude as the thermal energy of H⁺ and He⁺. As a result,

the current-voltage (I-V) curves for the two light ions overlap.

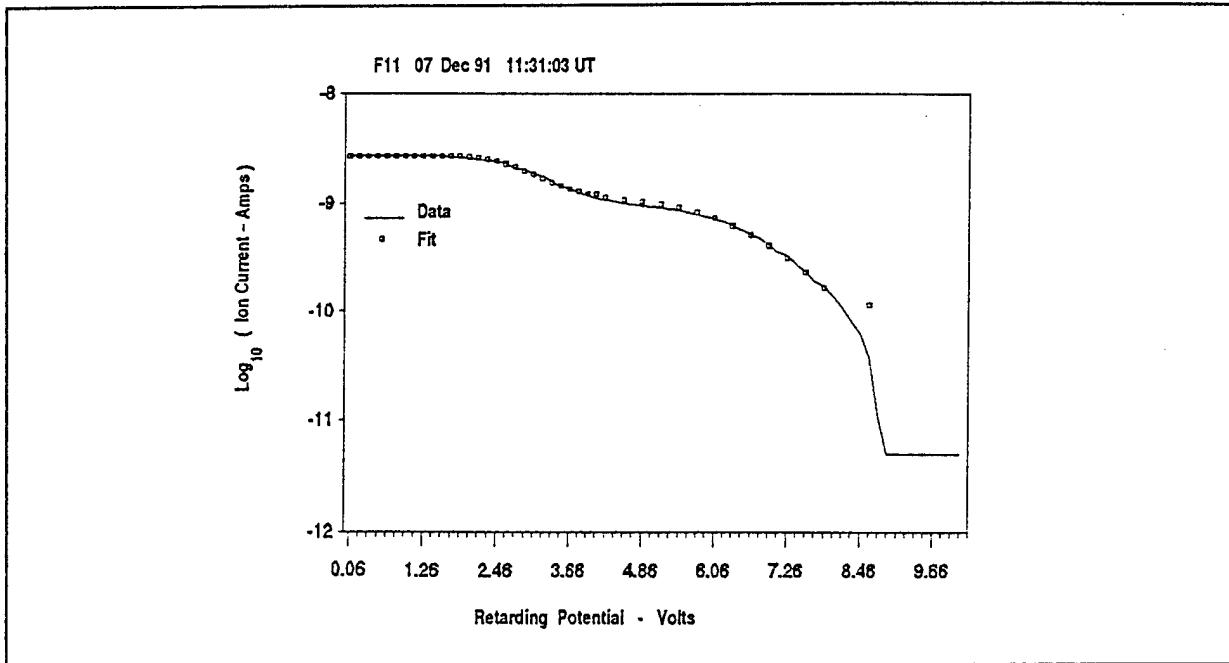


Figure 15. Sample of \log_{10} of the RPA Current Collected When Multiple Species are Present

The collected current (I) versus retarding potential (V) is a non-linear function. In general, the ion plasma parameters are obtained by fitting the measured current versus voltage values to the theoretical curve. Figure 15 shows a data sample of $\log_{10}(I)$ vs. V fit to a curve. The most accurate method of analyzing the I-V curve is to use an algorithm that varies the plasma parameter to minimize the difference between the data and the theoretical curve. For routine or operational use, a function minimization algorithm is impractical because of the amount of computing time required. As a result, various algorithms are used which look for critical pieces of the I-V curve and extract the parameters from those points.

There are several systematic problems related to recovering all of the desired plasma parameters from the RPA data. First, there is an instrument problem when the current to the collector is less than 10^{-10} amp. The time for the logarithmic electrometer to settle at the proper value increases as the current decreases. This is a more significant problem when the retarding voltage is sweeping from +12 V to -3 V. At +12 V, there is no detectable current. As the sweep begins to allow current to reach the collector plate, the electrometer is momentarily "stuck" at a null output. Several samples are taken which should report a current slightly above 10^{-11} amps instead of the null output which is reported. The first non-null output is less than the output that should be reported. When the sweep is from -3 V to +12 V, the problem is less severe but the electrometer output will again lag behind and report an output that is too high when the current is less than 10^{-10} Amps. The only solution to this problem is to ignore low output of the electrometer when fitting the I-V curve. For very low ambient densities, the output of the electrometer can still be used to determine the density because enough time elapses in the sweep for the electrometer to go to the correct current at steps between 0 V and -3 V on retarding screen.

A serious limitation of any analysis of the I-V curve exists when there is only one species (usually O⁺) present. For each species, the analysis is determined by a few critical data parameters: I_i ($x = -\infty$), the current collected when no ions of species "i" are retarded (assuming the spacecraft is supersonic with respect to the ions); $\partial I_i / \partial V$ ($x = 0$), the slope of the I-V curve when half of the ions are retarded; and V ($x = 0$), the retarding potential when half of the ions are retarded.

This means that three data values are being used to determine four geophysical parameters (T , ϕ_s , V_d , N_i). Without further information, it is not possible to determine these four geophysical parameters. With two species, we get three more data values to put into the analysis but only one additional parameter (N_i) to solve for. The standard solution to determining the geophysical parameters with one species is to make an assumption about either the potential of the aperture with respect to the ambient plasma (ϕ_s) or the component of the ion drift parallel to the aperture normal (V_d). The assumption that

is made is that $V_d = 0$ at geomagnetic latitudes equatorward of 50° N or 50° S. This assumption has proven to be excellent. Other studies have shown that the magnitude of V_d at low and mid-latitudes is usually less than 20 m/sec. Any error in this assumption leads to an error in ϕ_s of 0.3 V or less. At high latitude, the assumption is made that $\phi_s = 0$. This assumption would be impossible to use without the SENPOT system working as well as it does. Even with SENPOT, this assumption is a bit troublesome since ϕ_s often has a value of - 2 or - 3 V and changes by more than 1 V during a high latitude pass. The result is an error in V_d of 1 km/sec or more. A more sophisticated assumption might be used in the future.

For SSIES there is an additional, minor complication in the analysis of the RPA I-V curves. The voltage applied to the collector plate was made a fixed voltage with respect to the retarding grids. That means that the voltage on the collector with respect to the reference voltage for the electrometer was changing and a displacement current ($\partial V / \partial t$) was added to the measured current. Since this displacement current is a small and well known value (6×10^{-11} amps), it is easily removed from the data before analyzing the data for the geophysical parameters.

As mentioned above, there are several ways to analyze the RPA data. The method used in the operational DMSP code hosted at AFSFC consists of constructing the curve of $\partial I / \partial V$ vs. V by calculating the anti-log of the telemetry values and taking the difference between adjacent values. This is good approximation of $\partial I / \partial V$ because the data samples are evenly spaced with respect to V . For SSIES3 where the data samples are not evenly spaced with respect to V , this method will have to be modified. The data from such an analysis is shown in Figure 16.

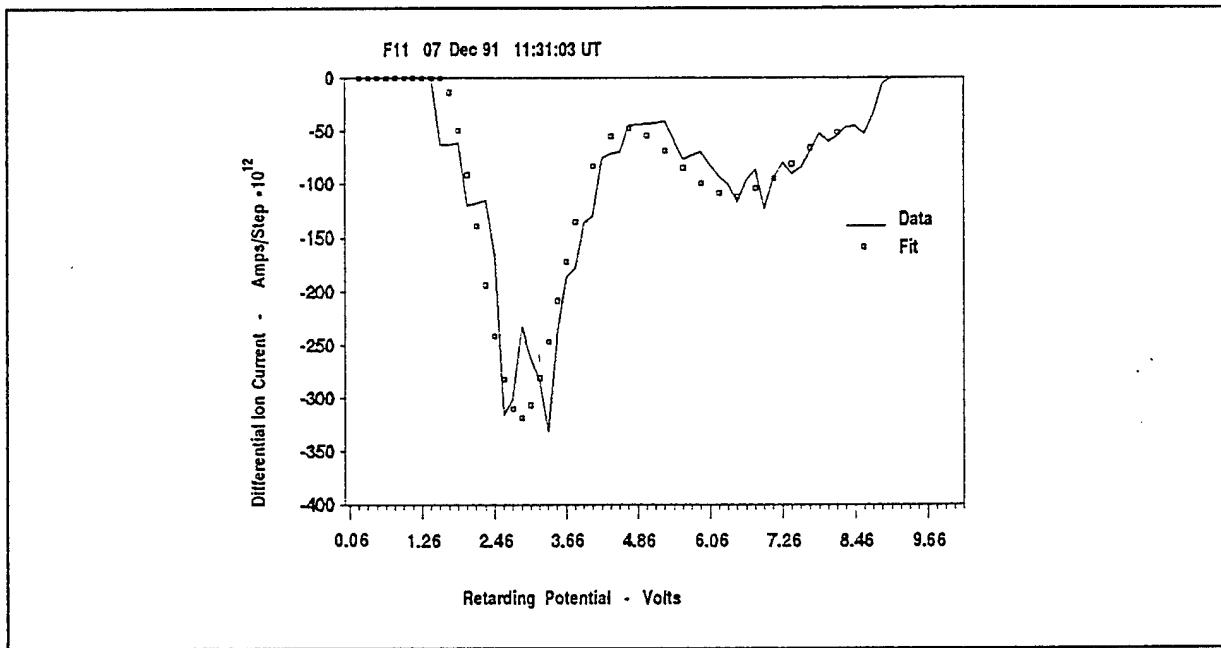


Figure 16. Differences (or Slope) of RPA Current Collected for Figure 15

The first step in the analysis of the $\partial I / \partial V$ data is to search for the peaks in the function. If only O⁺ is present, there is only one peak. If H⁺ and/or He⁺ is present, there are two peaks - a light ion peak and the O⁺ peak. The 5, 7 or 9 data points near the peak(s) are fitted to a second order polynomial in order to smooth the data. The values of $\partial I / \partial V$ calculated from the raw data do not form a smooth function because of the finite step size in the telemetry values for $\log_{10}(I)$ and because of noise in the environment while the sweep is being made. In the auroral zones, the environmental noise may be too large to achieve a meaningful analysis using any method. After a simple polynomial fit to each peak is constructed, the values of I , $\partial I / \partial V$ and V at the peaks are used to calculate the geophysical parameters. If there is only one peak, then there is only one polynomial fit. As a check, the geophysical parameters are put into the theoretical function and the difference between the data and the theoretical function at each data point is calculated. If the sum of the differences is too great, the solution for the given sweep is discarded as unusable and a null result is sent to the output.

For analysis performed at the University of Texas at Dallas, the RPA I-V curve is analyzed by doing a least squares

fit to the data. This means that an "error" parameter is minimized. The "error" parameter is obtained by calculating the difference between the data value for I and a theoretical values for I based on a set of geophysical parameters. Figure 17 shows an example of both measured currents and calculated, or "fitted" currents, for the same retarding potentials. The difference between measured and fitted current at each data point is multiplied by itself (or squared) and the sum of the squared values is calculated. Finally, the "error" parameter is the square root of this sum. The geophysical parameters are repeatedly adjusted until the "error" parameter is as small as it can get. If the size of the "error" is smaller than a pre-set limit, the final set of geophysical parameters are sent to the output. To minimize the processing time and to minimize errors related to the finite step size of the DMSP output, only data points near the maximum (maxima) in $\partial I / \partial V$ are used. The criteria for selecting those points varies based on the user's inputs. There are many methods of doing a least squares analysis. The one used by UTD is based upon the algorithm described by Powell¹⁷.

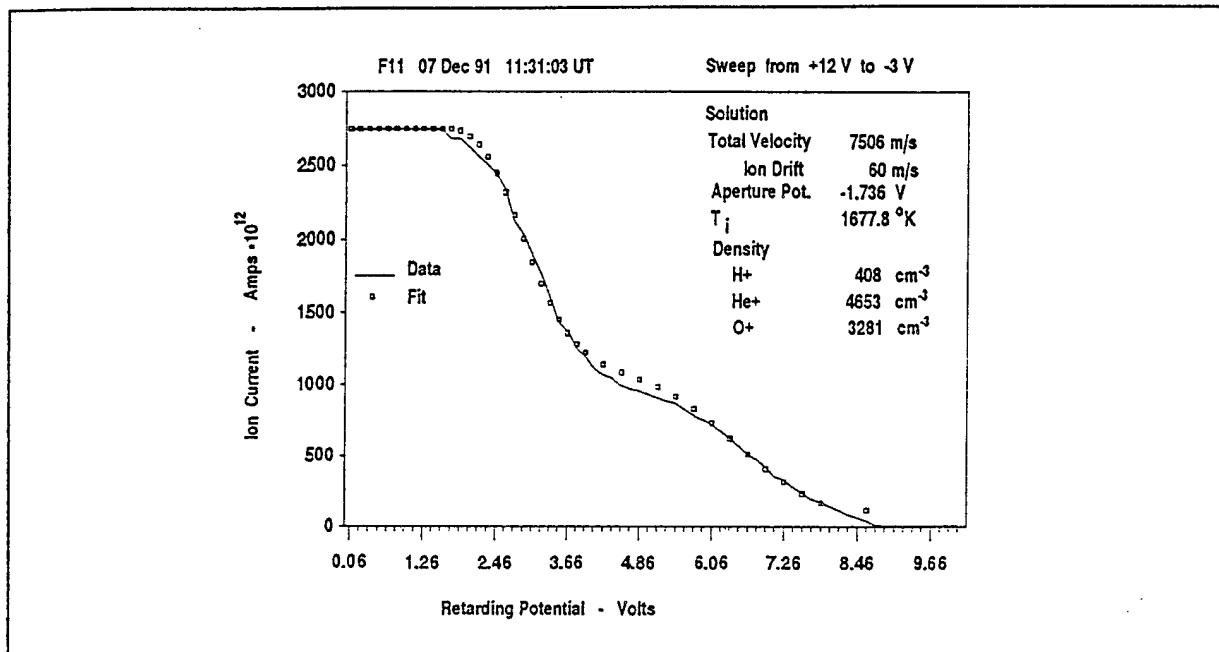


Figure 17. Same as Figure 15, Except RPA Current Collected is Shown

For analysis performed at PL/GP, a hybrid of the differencing method (a fast method) and the least squares method (a slow method) is used. First, the data are searched for the critical point of the current-voltage curve which is used to estimate the geophysical parameters. If a short CPU time is requested by the user, the outputs are determined from this search. If a long CPU time is allowed by the user, then the estimated geophysical parameters from the search are used as inputs to a least squares algorithm. The search of the current-voltage curve starts by calculating the ratio of the current at $V = +1$ to 0 V vs. the current at $V = -2.5$ to -3.5 V to determine if light ions are present in detectable quantities. If they are not, then N_{O+} is set equal to N_{Total} , which is calculated from $I(V = +1$ to 0 V). If they are present, then a search is made for a minimum in $\partial I / \partial V$ near $V = -3$ V and N_{O+} is calculated from the current at that point. From this point, the algorithm searches for the current that is half the current at the location that N_{O+} was determined. $\partial I / \partial V$ at the half current point is used to calculate the ion temperature T . If a least squares analysis has been requested, it starts with these parameters. The least squares method used by the PL/GP analysis is the simplex method described by Press et al.¹⁸

6.3 The Total Ion Trap (SM)

The conversion of the SM data from counts to total ion density values is simple in concept. The user needs only to know the "state" of the SM and the count level. The "state" of the SM is the range of the electrometer and whether the data value is from the electrometer output or from the difference amplifier. Unfortunately, it is not always simple to determine the "state" of the SM instrument. After a gap in the data, it is impossible to know the "state" of the SM instrument until a few seconds of data have passed. In many cases, it is possible to determine the "state" of the SM just after the data

gap by working backward from that point to the beginning of the data gap; but, that has not been implemented in any of the analysis algorithms. When the SM state is known, the conversion from an electrometer output is:

$$n_i = 20.77 \times 10^{(R-1)/2} \times Counts$$

where

$$\begin{array}{lcl} n_i & = & \text{ion density (cm}^3\text{)} \\ R & = & \text{Electrometer Range} \end{array}$$

When the SM output is known to be from the difference amplifier and the last electrometer output is available, the conversion is:

$$n_i = 20.77 \times 10^{(R-1)/2} \times \{ C_{\text{Stored}} + [Counts - 273] / 10.06 \}$$

where

$$C_{\text{Stored}} = \text{the last output of the electrometer before the difference amplifier was switched on.}$$

Once per second for SSIES and once every other second for SSIES2, the range of the electrometer and the wideband amplifier are sampled and a single output is created to indicate the two range values. This combined output is known as the range "flag." The two ranges are determined and the "flag" is constructed after the 10th SM sample for SSIES and after the 6th SM sample for SSIES2. The values of the ranges are determined when the flag is equal to or greater than the values given below. The values in Table 14 - 18 are given in this manner because the actual flag values vary by a few counts. Pre-flight calibration indicated that there is no difference in the output of this parameter for the three SSIES instruments. Likewise, pre-flight calibrations of the SSIES2 SM show no difference in the output of this parameter for the 5 SSIES2 instruments. Post-flight analysis of the SSIES data indicate a difference between the pre-flight calibration and the flight data. The post-flight of the F11 and F12 SM instrument has determined the flag output to be very close to the pre-flight calibration but there is no guarantee that future SSIES2 instruments will be as close. Post-flight analysis of the SM data will be needed to verify the table below.

Table 14. F8 SM Electrometer and Wideband Range When Flag Is Equal to/Greater Than:

		Electrometer		Range		
		1	2	3	4	5
Wide Band Amp Range	1	393	383	373	363	338
	2	313	303	292	282	272
	3	232	222	212	202	192
	4	152	142	131	121	111
	5	71	61	51	41	30

Table 15. F9 SM Electrometer and Wideband Range When Flag Is Equal to/Greater Than:

		Electrometer		Range	
		1	2	3	4
					5
Wide Band	1	396	386	376	366
Amp Range	2	313	304	294	284
	3	232	222	212	202
	4	150	140	130	120
	5	69	59	49	39
					25

Table 16. F10 SM Electrometer and Wideband Range When Flag Is Equal to/Greater Than:

		Electrometer		Range	
		1	2	3	4
					5
Wide Band	1	394	384	374	364
Amp Range	2	312	302	292	282
	3	230	220	210	200
	4	148	138	128	117
	5	65	55	45	35
					20

Table 17. F11 SM Electrometer and Wideband Range Flag When Is Equal to/Greater Than:

		Electrometer		Range	
		1	2	3	4
					5
Wide Band	1	383	373	363	353
Amp Range	2	303	293	283	273
	3	223	213	203	193
	4	144	134	124	114
	5	65	55	45	35
					20

Table 18. F12 SM Electrometer and Wideband Range When Flag Is Equal to/Greater Than:

		Electrometer	Range	1	2	3	4	5
Wide Band	1	385		375		366	356	346
	2	305		295		285	275	265
	3	225		215		205	195	185
	4	145		135		125	115	105
	5	65		55		45	35	20

Once the ranges are known and the value of N_i is known, the conversion of the SM wide band filter outputs to $\log_{10}(\text{rms}[N_i])$ is:

$$\log_{10}(\text{rms}[N_i])(f_i) = 0.00653 \times \text{Counts}_i - CF_i - 0.5(2 - RW - RE) + 11.517$$

where

$\log_{10}(\text{rms}[N_i])(f_i)$	-	Amplitude of density fluctuations (cm^{-3}) in the frequency band pass of filter i
Counts _i	-	Counts from Filter i
CF _i	-	Calibration Factor for Filter i (see Table 19 below)
RW	-	Range of the Wide Band Electrometer
RE	-	Range of the SM Electrometer

Table 19. SM Filter Calibration Factors

	Filter 1	Filter 2	Filter 3	Filter 4	Filter 5	Filter 6	Filter 7	Filter 8	Filter 9
F8	14.079	14.115	14.375	14.231	14.412	14.560	14.244	14.175	13.698
F9	13.746	13.811	13.883	13.896	14.018	14.112	14.092	13.995	13.504
F10	14.190	14.189	14.079	13.997	14.116	14.077	14.009	13.812	13.010
F11 - F15	14.079	14.115	14.375	14.231	14.412	14.560	n/a	n/a	n/a

6.4 The Spherical Langmuir Probe for Electrons (ELEC or EP)

The data shown in Figure 18 are typical of data collected by the EP sensor in the mid-latitude ionosphere. The acceleration region and retarding region to either side of where the applied voltage balances the plasma potential ($V_{\text{applied}} = -\phi_s$) is very similar to the theoretical response of the sensor. In addition to the cold ionospheric plasma ($T_e = 1000 - 2500 \text{ }^{\circ}\text{K}$), there may be a hot population of electrons ($T_e = 3000 - 15,000 \text{ }^{\circ}\text{K}$) which have escaped from the conjugate ionosphere and have interacted with the plasmaspheric plasma. Anytime the spacecraft is in sunlight, there is also a population of photoelectrons.

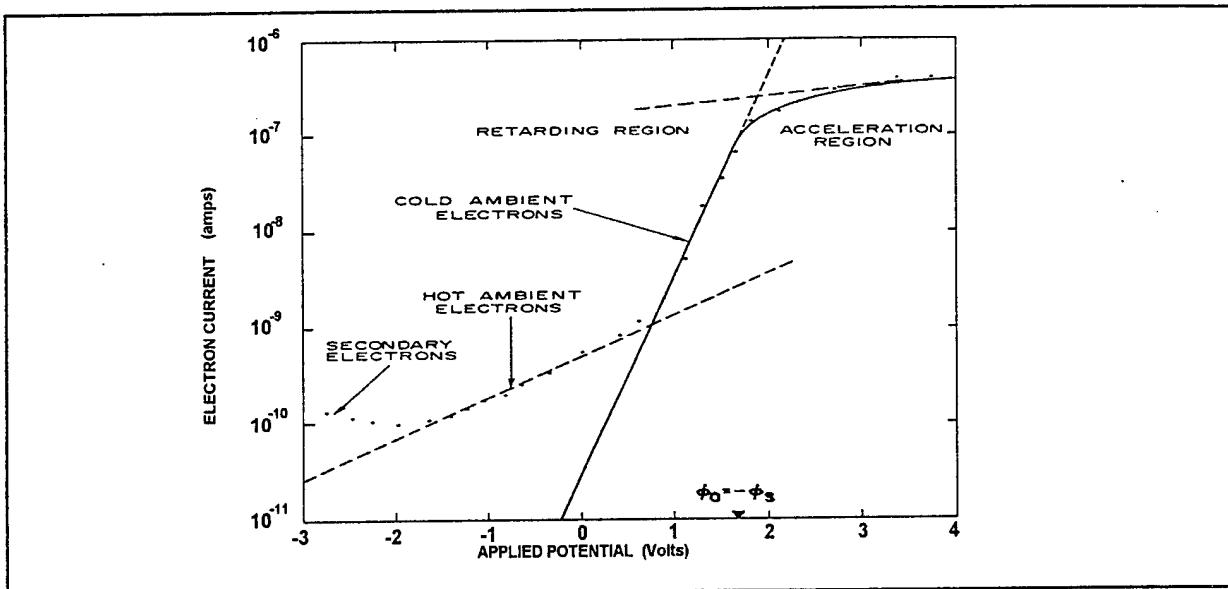


Figure 18. EP Current Collected and Straight Line Fit

The processing of the DMSP EP data starts with an elimination of data points caused by photoelectron and hot electrons. After this is done, a straight line is fit to the data points in the retarding region caused by the cold electrons. The slope of this line is used to determine the temperature of the cold electrons. Another straight line is fit to the four points at the highest acceleration voltage. The voltage at which the two lines intersect gives a reasonable approximation to the plasma potential. In theory, the $\log_{10}(I)$ vs. V curve in the acceleration region should not be a straight line. However, since the electrons collected in the acceleration region tend to drive the spacecraft potential negative, a straight line usually fits the data quite well. The current corresponding to the voltage at which the two straight lines intersect is used to calculate the plasma potential (ϕ_s) and the electron density (n_e).

Since the EP sensors has a single grid, the potential in the holes of the grid is slightly different from the potential on the wires of the grid. The potential experienced by the electrons will be slightly shifted toward the plasma potential. Because the applied voltages are used in the data reduction, the calculated electron temperatures will be slightly higher than the true electron temperature.

6.5 The Microprocessor

The microprocessor is the electronic center of the SSIES/SSIES2/SSIES3 system. It receives information from the spacecraft and from the instruments. It changes the settings of the system as necessary. It prepares the output buffer for the spacecraft system to read out the data and add it to the spacecraft telemetry. These functions occupy only a small part of the microprocessor's capabilities. With some of the additional capability, the microprocessor stores the Langmuir probe and the ion retarding potential analyzer data, calculates the ion and electron temperature, calculates the ion and electron densities and estimates the instruments potential with respect to the ambient plasma.

The microprocessor collects more data from the sensors than can be telemetered to the ground. Analog measurements are converted to 10 bits of digital data, of which at least 9 are significant. Only 9 bits are telemetered. The microprocessor receives 25 current measurements from the Langmuir probe and 149 current measurements from the RPA each second. Twenty-four Langmuir probe measurements are telemetered and one is discarded. Of the RPA current measurements, 24 are telemetered, and 125 are averaged in groups of 5 to create 25 samples for the in-flight ion parameter calculations. The data analysis algorithms are relatively simple due to the limited storage and processing capacity of the microprocessors. The RPA data is analyzed with the difference technique illustrated in Figure 16 and the Langmuir probe data is analyzed by fitting the acceleration and retarding regions to two straight lines as illustrated in Figure 18. If the microprocessor cannot find a solution within the allowed time between its control functions, then a null solution is sent to

the output buffer.

The microprocessor collects data from an entire RPA or Langmuir probe sweep before the ion or electron parameters can be determined. The electron data are analyzed during the first second following the sweep, and the ion data during the second second. The telemetered values for the plasma parameters are updated at different times during the four seconds after the sweep data are collected and placed in the telemetry. The timing of updates is as follows: Second 1: Electron temperature, spacecraft potential derived from electron data. Second 2: Electron, H⁺, and O⁺ density, downrange drift velocity and spacecraft potential computed from the ion data. Second 3: H⁺ and O⁺ temperature.

The calculated values obtained by the microprocessor are very similar to values obtained by ground-based software analyzing the telemetry values of RPA and Langmuir probe currents. Since the ground-based algorithm is almost identical to the microprocessor-based algorithm, the microprocessor value might be slightly better because it has one more bit in the measurements to work with. The microprocessor based algorithm is able to achieve good results with its simple algorithm for the RPA analysis because it has much more data to work with than does the ground-based software. For SSIES2 and SSIES3, it is possible to improve the algorithms and load a new version via a link from the ground to the spacecraft. So far, that has not been found to be necessary. To date, the only change in the SSIES2 microprocessor program that has been initiated is a reconfiguration of the telemetry format from that shown in Table B1 to that shown in Table B2. This change is necessary because for F12 through F15 only 80 words (720 bits) of each data frame are sent to the ground.

7. PERFORMANCE, CALIBRATION AND VALIDATION OF SENSORS

The SSIES and SSIES2 sensors on F8 through F12 have performed well. The RPA and Langmuir probe (EP) sensors on F8 stopped working in Nov 87 and July 88 respectively. The RPA and EP on F9 stopped working shortly after launch. These problems have been traced to a bad connector inside the main electronics box and was corrected for F10 and later flights. The driftmeters and SM sensors are on all satellites to date. The EP and the RPA on F10 through F12 have performed without any problems. The raw EP data on F11 and F12 are usually not available due to a limitation in the telemetry assignment. The microprocessor output from the F11 EP sensor was not available from Aug 93 to May 94 due to a bug in the microprocessor program. The microprocessors and SENPOT systems of SSIES and SSIES2 on all the spacecraft to date have performed well.

All of the sensors have experienced degraded performance when the ambient density drops below 10^4 cm^{-3} . The driftmeter and the SM sensors register a higher level of noise. The output of log electrometer for the RPA and Langmuir probe tends to lag behind the actual currents collected during the sweeps. Below an ambient density of 10^3 cm^{-3} , none of the outputs except the total ion density of the SSIES or SSIES2 can be relied upon. Also, when the H+/He+ density becomes greater than the O+ density, the output of the driftmeter and the SM sensors cannot be relied upon.

7.1 Designed Measurement Precision and Accuracies

The design criteria for the various plasma parameters are given in Table 3. The various instruments of the SSIES, SSIES2 and SSIES3 systems measure current which can be converted to ion densities by multiplying the measurement by a constant. The accuracy and range of the measured currents are limited only by the design of the conversion of the analog signals to digital telemetry. The analog signals within the system are designed and have been tested with standard bench test equipment to have a higher degree of precision than the digital telemetry. Most of the other parameters are limited by the ability of the software to derive values such as temperature. Analysis of flight data indicates that the SM and RPA ion densities match exactly except when H+ and/or He+ are present in significant ratios to O+. The electron density is a value derived by software from the EP currents at a grid voltage calculated to be at the plasma potential. Due to an uncertainty in the calculation of the plasma potential, the calculated electron density is often different from the ion densities by as much as a factor of 2. Analysis of flight data from the ion drift meter has shown the precision of the current ratios to be at least as precise as the telemetry but there is a tendency for the zero level to vary slowly over an orbit by an amount equivalent to 200 m/sec. Future analysis will determine that factor better.

7.2 Ground Calibration

There is no ground calibration of the SSIES system beyond the bench testing of the analog circuits prior to assembly into the SSIES system.

7.3 In-Flight Validation

The ion densities were compared with density measurements obtained simultaneously with the incoherent-scatter radar located at Millstone Hill, Massachusetts, USA. Twenty-four separate sets of radar were obtained and compared with the ion densities obtained with the SM sensor on F8 and F9. For 80% of the cases, the SSIES measurement agreed with the radar measurement to within 20 percent, which is the limit of the radar's accuracy at 840 km altitude. In no case was there a difference greater than 35 percent. There is no explanation for why there is a significant difference in 20 percent of the cases. The results of this study were never written up as a technical report.

The horizontal ion drifts have been compared with ion drift measurements obtained simultaneously with the incoherent-scatter radar at Millstone, Hill, Massachusetts. The analysis of the two data sets has not been completed yet. Preliminary results show that the SSIES ion drift values are quite accurate.

8. DATA ARCHIVING

The DMSP mission sensor data are received on the ground as part of the OLS data stream. In addition to the mission sensor data and the OLS data, the data stream contains general information such as the timing of the mission sensor data relative to the OLS time. The data may be received either by a real-time receiver, which is often a mobile, tactical unit, or it may be received by a permanent site which obtains data from the flight tape recorders. The data from the flight recorders is sent to Global Weather Central at Offutt AFB, NE. Since the beginning of the SSIES data, all SSIES data is stripped out of the data stream and placed on a magnetic tape. The magnetic tape is sent to PL/GPS. Since 1992, the full data stream is copied to a magnetic tape which is sent to NGDC/NOAA. GWC maintains the DMSP data on file for a period of a few days to a few weeks, but it does not maintain a permanent archive of the data.

All SSIES and SSIES2 data are archived at PL/GPS and at the Univ of Texas at Dallas. While the archive contains the raw SSIES or SSIES2 telemetry data, users may find it more useful to obtain data outputs of programs such as the one which analyzes the ion driftmeter data for the electrostatic potential across the high latitude regions¹⁹ and/or the ground processing program which gives geophysical quantities for all SSIES and SSIES2 outputs²⁰. These data are available from PL/GPS.

Beginning sometime in 1995, all SSIES2 and SSIES3 data will be archived at the National Geophysical Data Center (a component of NOAA), Boulder, CO. These plans call for the archive and distribution of all DMSP data including the data from the OLS. Decimated or "quick look" versions of the data will be available over the Internet by anonymous ftp (a unix file transfer protocol) from node ftp.ngdc.noaa.gov. Complete versions of the data can be obtained by sending a request to NGDC and paying the cost of copying and mailing the data. As of the writing of this document, this archive is not yet functioning.

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Appendix A SSIES Telemetry Format

The SSIES data are placed in an output buffer during each second. At the beginning of the next second of operation, the data is transferred from the SSIES output buffer to the OLS data formatter. The beginning of this transfer is called the READGATE. The SSIES telemetry format is not subject to change.

The SSIES data placed in the output buffer consists of 120 9-bit words (1080 bits per second). Some of the words are used to indicate the status of the SSIES system, some of the words are data samples and some of the words are results from analysis of the data words by the onboard microprocessor. The contents of the output buffer are given in Table A1. Below are definitions of the 9-bit words. Most words are put into the output buffer every second, but some words are put into the output buffer when the cycle counter is an odd number (Cycle 1) and some words are put into the output buffer when the cycle counter is an even number (Cycle 2).

DEFINITION OF TM DATA WORDS:

Cycle 1 ID (Word 1, Cycle 1)

MSB C	MF	MF	MF	TMF	B/M	CLK	PRF	LSB 1
----------	----	----	----	-----	-----	-----	-----	----------

C = 1 or 0, MSB of Cycle Counter

MF (bits 5-7) = Mode Flag

= 0, EP Mode A; = 1, EP Mode B; = 2, EP Mode C; = 3, EP Mode D; = 4, EP Mode E

TMF = Test Mode Flag = 0 (OFF) or 1 (ON)

B/M = 1 during 8 sec electron sensor bias-setting sweep cycle, otherwise 0

CLK = 1 if sweep clocks are on (normal operation of EP and RPA)

PRF = 1 if program will restart with next cycle beginning

Cycle 2 ID (Word 1, Cycle 2)

MSB C	C	C	C	C	C	C	C	LSB 0
----------	---	---	---	---	---	---	---	----------

C = bits 1 - 8 of the Cycle Counter; bit 0 is always 0 when Cycle Counter is even.

The cycle counter counts the number of seconds since the beginning of a SSIES cycle. The number of seconds in a cycle depends on the mode. The internal SSIES cycle counter can run from 0 to 1023 (10 bits). The 9 LSB's of the cycle counter are contained in the cycle 2 ID. The MSB of the cycle counter is contained in the MSB of word 1 of the following cycle 1. The beginning of any cycle is when the cycle counter is 1. In Modes A, B, and E, the cycle is 128 seconds long. In Modes C and D, the cycle is 1024 seconds long. In Modes C and D, the MSB of the following cycle 1 ID is concatenated with the cycle 2 ID to get the cycle counter value.

OLS Cmd (Word 70, Cycle 1)

MSB 0	C	C	C	C	C	C	C	LSB C
----------	---	---	---	---	---	---	---	----------

C = Bits 7-0 of Last SSIES command sent from OLS. See SSIES command table for meaning of commands.

DSM Cmd (Word 70, Cycle 2)

MSB S	F	F	F	F	D	D	D	LSB D
----------	---	---	---	---	---	---	---	----------

S = VBIAS/SENPOT FLAG; 0 = VBIAS MODE, 1 = SENPOT MODE (S9/F8 and S10/F10 only)

F = 4 LSB'S OF DSM CMDS 20(HEX) -3F(HEX)

D = 4 LSB'S OF DSM CMDS 30(HEX) - 3F(HEX)

The two four bit fields independently update. Command 22(HEX) is used as the Test Mode enable and will not echo in this word. All other commands 20 (HEX) to 3F(HEX) echo. Command 21(HEX) and Command 23 (HEX) echo only for 1 second and Word 70 then returns to its previous state. See SSIES DSM command table for explanation of commands.

ACRONYM WORD/CYCLE DESCRIPTION

SM Data	2,7,etc/all	Total Ion Trap (SM) Electrometer/Amplifier Output
RPA Data	3,8,etc/all	Ion RPA Log Amplifier Output of current to collector.
EP Data	4,9,etc/all	Electron Probe Log Amplifier Output of current to collector
EP Sweep Monitor	5,25,etc/all	Voltage Applied to Electron Retarding Grid (Volts = 0.16 * (Counts - 256))
RPA Sweep Monitor	15,35,etc/all	Voltage Applied to Ion RPA Retarding Grid (Volts = 0.16 * (Counts - 256))
DM Data	6,16,etc/all	Drift Meter Offset Output
SM Filter	10,11,etc/all	Output from Filters Connect to SM Collector
SM Range	51/all	Indicator of Range Setting for SM Electrometer/Amplifier
DM LLA	60/1	Output of Drift meter log amp LLA (Log(Amp) = 0.01*Counts - 10.73)
DM LLB	60/1	Output of Drift meter log amp LLB (Log(Amp) = 0.01*Counts - 10.73)
DM Zero	61/1	Drift meter zero level
DM Temp	61/2	DSM electronics temperature (= Counts / 10)
Test 1 Flag	71/1	Indicates if SSIES is in Test 1 Mode
Test 2 Flag	71/2	Indicates if SSIES is in Test 2 Mode
EP Monitor	80/1	Microprocessor Flags for EP Data Analysis Bit 8 (MSB) = Vp outside sweep range Bit 7 = Io out of range Bit 6 = Vp outside -10 to +41 V Bit 5 = TE > 10,220 °K Bit 4 = Insuff. data range (<1.5 V) Bit 3 = I high. All TM values > 250. Bit 2 = I low. All TM values < 250. Bit 1 = Slope high (TE < 800) Bit 0 (LSB) = Slope low (TE > 10,000)
RPA Monitor	80/2	Microprocessor Flags for RPA Data Analysis Bit 8 (MSB) = Bad Min/Max current ratio Bit 7 = Bad Temperature ratio Bit 6-5 = Specie flags (0=both,1=H+,2=O+,3=unused) Bit 4 = Vp Ion calculation overflow Bit 3 = TO+ calculation overflow Bit 2 = NO+ calculation overflow Bit 1 = TH+ calculation overflow

Bit 0 (LSB) = NH+ calculation overflow

V(ap) Monitor	81/all	Measured voltage on Ion Array
Vbias+Vip Monitor	90/all	Setting levels for V(BIAS) + V(IP) Bits 7-6 = V_{IP} setting Bit 5 = spare. Should be 0. Bits 4-0 = V_{BIAS} setting
MEP Temp 1	91/1	Temperature @ MEP Electrometer ($^{\circ}\text{C} = \text{Counts}/4 - 35$)
MEP Temp 2	91/2	Temperature @ MEP ADC ($^{\circ}\text{C} = \text{Counts}/4 - 35$)
T(E)	100/1	Electron Temperature Calc. by Microprocessor
N(E)	100/2	Electron Density Calc. by Microprocessor
T(H+)	101/1	H+ Temperature Calc. by Microprocessor
N(H+)	101/2	H+ Density Calc. by Microprocessor
T(O+)	110/1	O+ Temperature Calc. by Microprocessor
N(O+)	110/2	O+ Density Calc. by Microprocessor
Current Monitor	111/1	Current (+28 V) Input from Spacecraft (mA = Counts * 1.33)
Vsp	111/2	Calc. Down-range Relative Plasma Velocity
Vp - EP	120/1	Vehicle Potential from Calc. of EP Data
Vp - RPA	120/2	Vehicle Potential from Calc. Ion RPA Data

NOTE 1: Ion Sensor values replaced with dummy data during Test 1 Mode. Electron Sensor values replaced with dummy data during Test 2 Mode

Table A1 Standard SSIES Telemetry Data Format

Word										Cycle
1 - 10	Cycle 1 ID	SM Data	RPA Data	EP Data	EP Sweep Monitor	DM Data Vertical	SM Data	RPA Data	EP Data	SM Filter 7
	-----									1
	Cycle 2 ID			"	"	Ion Sweep Monitor	DM Data Horizontal	"	"	SM Filter 3
										2
10 - 20	SM Filter 5	"	"	"	"					
21 - 30	SM Filter 1	"	"	"	"	EP Sweep Monitor	DM Data Vertical	"	"	SM Filter 8
										1
										2
31 - 40	SM Filter 6	"	"	"	"	RPA Sweep Monitor	DM Data Horizontal	"	"	SM Filter 4
										1
										2
41 - 50	SM Filter 2	"	"	"	"	EP Sweep Monitor	DM Data Vertical	"	"	SM Filter 9
										1
										2
51 - 60	SM Range	"	"	"	"	RPA Sweep Monitor	DM Data Horizontal	"	"	DM LLA

										DNLLB
										2
61 - 70	DM Zero	SM Data	RPA Data	EP Data	EP Sweep Monitor	DM Data Vertical	SM Data	RPA Data	EP Data	OLS Cmd
	-----									1
	DM Temp									-----
										2
71 - 80	TEST 1 FLAG	"	"	"	"	RPA Sweep Monitor	DM Data Horizontal	"	"	EP Monitor
	-----									1
	TEST 2 FLAG									-----
										2
81 - 90	V(ep) Monitor	"	"	"	"	EP Sweep Monitor	DM Data Vertical	"	"	V(bias) +
										V(IP) Monitor
										1
										2
91 -100	MEP Temp 1	"	"	"	"	RPA Sweep Monitor	DM Data Horizontal	"	"	T(E)

	MEP Temp 2									
101-110	T(H+)	"	"	"	"	EP Sweep Monitor	DM Data Vertical	"	"	T(O+)

	N(H+)									
111-120	Curr Monitor	"	"	"	"	RPA Sweep Monitor	DM Data Horizontal	"	"	Vp - EP

	Vsp									Vp - RPA
										2

Table A2 SSIES OLS Commands

HEX Value	Command	Action	HEX Value	Command	Action
10	Program/Sweep Cycle Re-Set	$V_{IP} = 0$, EP Mode = A	18	Step $V_{BIAS} +2$ V	
11	EP Mode A		19	Step $V_{BIAS} -2$ V	
12	EP Mode B		1A	Step $V_{BIAS} +4$ V	
13	EP Mode C		1B	Step $V_{BIAS} -4$ V	
14	EP Mode D		1C	Step $V_{IP} +1$ V	Wraps from 0 to -3 V
15	EP Mode E		1D	Step $V_{IP} -1$ V	Wraps from -3 to 0 V
16	Step $V_{BIAS} +1$ V	Stepping Upward, V_{BIAS} stops at +28 V	1E	Clock On - CAL Only	Sweep clocks are on.
17	Step $V_{BIAS} -1$ V	Stepping Downward, V_{BIAS} wraps from -3 V to -28 V	1F	Clock Off - CAL Only	Sweep clocks are frozen

Table A3 SSIES DSM Commands

HEX Value	Command	Action	HEX Value	Command	Action
20	RNGRE	Restricted Ranging for SM Wideband Amplifier	33	DREP15	DM Repeller Pot. = 1.5 V
21	VBIAS MODE	SENPOT OFF, VBIAS set by Microprocessor or Command	34	DREP20	DM Repeller Pot. = 2.0 V
22	TEST MODE	On/Off	35	DREP25	DM Repeller Pot. = 2.5 V
23	SENPOT MODE	SENPOT sets VBIAS	36	DREP30	DM Repeller Pot. = 2.0 V
24	RNGFR	Free Ranging for SM Wideband Amplifier	38	0WIGLO	DM H+ Mode, Start Steps at 0 V, Low Wiggle = 50/400 mV (H+DERIV/H+DS)
28	RNG01	SM Wideband Amp Fixed at Range 1	39	0WIGHI	DM H+ Mode, Start Steps at 0 V, High Wiggle = 100/800 mV (H+DERIV/H+DS)
29	RNG02	SM Wideband Amp Fixed at Range 2	3A	1WIGLO	DM H+ Mode, Start Steps at 1 V, Low Wiggle
2A	RNG03	SM Wideband Amp Fixed at Range 3	3B	1WIGHI	DM H+ Mode, Start Steps at 1 V, High Wiggle
2B	RNG04	SM Wideband Amp Fixed at Range 4	3C	2WIGLO	DM H+ Mode, Start Steps at 2 V, Low Wiggle
2C	RNG05	SM Wideband Amp Fixed at Range 5	3D	2WIGHI	DM H+ Mode, Start Steps at 2 V, High Wiggle
30	DREP00	DM Repeller Pot. = 0.0 V	3E	3WIGLO	DM H+ Mode, Start Steps at 3 V, Low Wiggle
32	DREP10	DM Repeller Pot. = 1.0 V	3F	3WIGHI	DM H+ Mode, Start Steps at 3 V, High Wiggle

Appendix B SSIES2 Telemetry Format

This section describes the format of SSIES2 data. When the SSIES2 is operating from the program in its PROM, the standard format, given in Table B1, is output. When the SSIES2 is operating from a program loaded into its RAM, another format is possible. In particular the format described in Table B2 has been developed and has been utilized for the first few weeks of F12 operation. The pre-flight plan was to utilize the format in Table B2 for all F12 SSIES2 data but a problem was discovered with the SSIES2's RAM. The RAM is susceptible to Single Event Upsets (random changes in bits) when exposed to the penetrating particles of the South Atlantic Anomaly region.

The SSIES2 data is placed in the output buffer which consists of 120 9-bit words (1080 bits per second). This is very similar to the SSIES data format. The major difference is that the SSIES2 data words are not placed in the buffer in the order in which they are sampled. The other difference is that the spacecraft does not shift out all of the data words to the OLS data formatter. For F11, the OLS telemetry allocation is 21 36-bit words. Thus the first 84 9-bit words of this format are output to the telemetry. For F12, the OLS telemetry allocation is 20 36-bit words. Thus when SSIES2 is operating with the default program, only the first 80 9-bit words of this format are output to the telemetry.

The contents of the output buffer for the default SSIES2 operating program are given in Table B1. Below are definitions of the 9-bit words that are different than the SSIES words. Most words are put into the output buffer every second, but some words are put into the output buffer when the cycle counter is an odd number (Cycle 1), some words are put into the output buffer when the cycle counter is an even number (Cycle 2), and some of the DSM multiplex word are put into the output buffer every 4th, 8th or 16th count.

DEFINITION OF TM DATA WORDS:

Cycle 1 ID (Word 1, Cycle 1)

MSB C	MF	MF	MF	TMF	B/M	CLK	PRF	LSB 1
-------	----	----	----	-----	-----	-----	-----	-------

C = 1 or 0, MSB of Cycle Counter

MF (bit 5-7) = Model Flag

= 0, Mode A; = 1, Mode B; = 2, Mode BS; = 3, Mode C; = 4, Mode D
= 5, Mode DS; = 6, Mode E

TMF = Test Mode Flag = 0 (OFF) or 1 (ON)

B/M = 1 during 8 sec electron sensor bias-setting sweep cycle, otherwise 0

CLK = 1 if sweep clocks are on (normal operation of EP and RPA)

PRF = 1 if program will restart with next cycle beginning

Cycle 2 ID (Word 1, Cycle 2) same as SSIES

Config 1 ID (Word 2, Cycle 1)

Bit 8 (MSB) Microprocessor running from program in RAM (=1) or PROM (=0)

Bit 7 Program Test Mode (=1) or Flight Mode (=0)

Bits 6-0 Program Version Number (=5 for program stored in PROM, =6 for Modified Output Format, see Table B2)

Config 2 ID (Word 2, Cycle 2)

Bit 8 (MSB) RAM Error

Bit 7 Indicates whether the program is sending the normal output data (=0) or is sending a dump of the contents of RAM (=1).

Bit 6 Check Sum Error

Bit 5 Indicates if the program is running in normal mode (=0) or has stopped to received an uplink set of code (=1).

	Bit 4	Indicates whether word 13 to 36 contain RPA data (=0) or contain EP data (=1). See note (1) below.
	Bit 3	Spare
	Bit 2-0	SSIES2 serial number
OLS Cmd	(Word 3, Cycle 1)	Same as SSIES output format See SSIES2 command table for meaning of commands.
DSM Cmd	(Word 3, Cycle 2)	Same as SSIES output format. (See DSM2 command table for meaning of commands. Unlike SSIES, whole command is stored.)
Current	(Word 4, Cycle 1)	Input Current (mA) = Raw Dat * I_{cal}
MEP Temp	(Word 4, Cycle 2)	Temperature in MEP on Analog/DSM board = (Raw Data / T_{calD}) - T_{cal0} °C

where

		S/N 01	S/N 02	S/N 03	S/N 04	S/N 05	
	I_{cal}	2.24	2.36	2.36	1.91	2.18	
	T_{calD}	4.00	4.14	4.14	4.00	3.98	
	T_{cal0}	45.00	41.3	42.4	55.0	36.6	
RPA Temp	(Word 5, Cycle 1)	Temperature from Thermister on back of RPA Sensor Housing					
EP Temp	(Word 5, Cycle 2)	Temperature from Thermister on EP pre-amp Housing at foot of EP boom					
V _{ap}	(Word 6, Cycle 1)	Voltage of ion array aperature = 0.16 * (Raw Data - 256)					
V(IP/bias)	(Word 6, Cycle 2)	Bits 7-6	V(IP) = -Raw Data V(bias) = Raw Data - 3				
RPA Monitor	(Word 7, Cycle 1)	Same as SSIES					
T(H ⁺)	(Word 8, Cycle 1)	Same as SSIES, °K = 20 * Raw Data					
N(H ⁺)	(Word 8, Cycle 2)	Same as SSIES $\log_{10}(n_i) = (0.01 * \text{Raw Data}) + 1$					
T(H ⁺)	(Word 9, Cycle 1)	Same as SSIES, °K = 20 * Raw Data					
N(H ⁺)	(Word 9, Cycle 2)	Same as SSIES $\log_{10}(n_i) = (0.01 * \text{Raw Data}) + 1$					
V _p - RPA	(Word 10, Cycle 1)	Plasma potential calculated onboard from RPA data, volts = 0.02 * Raw Data - 6					
V _{sp}	(Word 10, Cycle 2)	Plasma drift velocity downrange calculated on from RPA data, m/s = (40 * Raw Data) - 10,000					
EP Monitor	(Word 11, Cycle 1)	Microprocessor Flags for EP Data Analysis - Same as SSIES.					
V _p - EP	(Word 11, Cycle 2)	Plasma potential calculated onboard from EP data, volts = 0.1 * Raw Data - 10					
T(E)	(Word 12, Cycle 1)	Electron temperature calculated onboard from EP data, °K = 20 * Raw Data					
N(E)	(Word 12, Cycle 2)	Electron density calculated onboard from EP data,					

$$\text{cm}^{-3} = ((4.9 \times 10^{11})/T_e) * 10^{(0.06 * \text{Raw Data}/5 - 10)}$$

where T_e = electron temperature in $^{\circ}\text{K}$

RPA Current Data	(Words 13-36)	Current Collected by RPA - Same as SSIES (Can be switched with EP Current Data) $\log_{10}(\text{amps}) = 0.01 * \text{Raw Data} - 11.30103$
SM Data	(Words 37-48, Words 73-84)	Output of SM Electrometer/Amplifier - Same as SSIES
DM Data	(Words 49-60)	Output of Driftmeter - Normal mode is the same as SSIES
EP Current Data	(Words 85-108)	Current Collected by EP - Same as SSIES (Can be switched with RPA Current Data) $\log_{10}(\text{amps}) = 0.01 * \text{Raw Data} * 6/5 - 10.$
RPA Sweep V	(Words 109-114)	RPA Sweep Monitor - Same as SSIES
EP Sweep V	(Words 115-120)	EP Sweep Monitor - Same as SSIES
Multiplex Data	(Words 61-72)	Multiplex Data from DSM
Word 61	Odd Seconds	Even Seconds
Word 62	DM FIBA 6	Subcom 1
Word 63	DM FIBA 5	Subcom 2
	DM FIBA 4	DM Log Level
		LLA(Sec=4*N+2), LLB(Sec=4*N)
Word 64	DM FIBA 3	Drift Signal
Word 65	DM FIBA 2	SM EL/WIBAN1 Range
Word 66	DM FIBA 1	WIBAN2 Range
Word 67	SM FIBA 6	SM FIBA 6
Word 68	SM FIBA 5	SM FIBA 5
Word 69	SM FIBA 4	SM FIBA 4
Word 70	SM FIBA 3	SM FIBA 3
Word 71	SM FIBA 2	SM FIBA 2
Word 72	SM FIBA 1	SM FIBA 1
Second	Subcom 1	Subcom 2
16*N+2	REG3A	REG3B
16*N+4	REG3C	REG3D
16*N+6	REG2A	REG2B
16*N+8	REG2C	REG2D
16*N+10	REG1A	REG1B
16*N+12	REG1C	REG1D
16*N+14	Sensor Temp (5)	Electronics Temp (5)
16*N+16	DM/FIBA Flag	SENPOT Flag
(N=any integer)	0 = DM/FIBA on 511 = DM Normal or H+ Mode on	0 = EP Bias Setting on 511 = SENPOT mode on

For S/N 01 (F11) Only

$$\text{Sensor Temperature (}^{\circ}\text{C}\text{)} = 125 * (0.01 * \text{Raw Data} + 0.02226 * V_{\text{ap}} - 1.51))$$

DSM Electronic Temperature (°C) = 98.4 * (0.01 * Raw Data + 0.02226* V_{ap} - 1.51)

where V_{ap} = aperture potential in Volts.

For S/N 02 to 05

Sensor Temperature (°C) = 0.888245 * Raw Data - 134.3112 (+/- 2° C)

DSM Electronics Temperature (°C) = 0.98894 * Raw Data - 144.2255 (+/- 2° C)

NOTES:

- (1) The RPA Current Data which is normally found in words 13 to 36 can be swapped with the Electron Probe Current Data which is normally found in words 85 to 108. Whether these data are in their normal locations or are swapped is determined by a command received from the ground. If the two data sets are swapped, then a flag is set in the CONFIG 2 ID word.
- (2) When the telemetry allocation is 21 36-bit words, these words are not placed in the telemetry stream which is recorded and transmitted to the ground.
- (3) When the telemetry allocation is 20 36-bit words, these words are not placed in the telemetry stream which is recorded and transmitted to the ground.
- (4) Driftmeter data Alternates between Vertical and Horizontal Drift only in Normal Mode. The Drift data has a different meaning in H+ and in DM/FIBA Modes.
- (5) The Sensor Temperature in the Multiplex data is the temperature on the pre-amplifier in the back of the SM sensor case. The DSM temperature is the temperature in the DSM electronics box.

For Tables B1 and B2

>>>>> I indicates that the word contains the same type data as the word to the left in the table.

Table B1 Standard SSIES2 Telemetry Data Format

Word														Cycle
1 - 12	Cycle 1 ID	Config 1 ID	OIS Cmd	Current	RPA Temp	Vap	RPA Monitor	T(H+)	T(O+)	Vp-RPA	EP Monitor	TE	1	
	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	
	Cycle 2 ID	Config 2 ID	DSM Cmd	MEP Temp	EP Temp	V(IP/bias)	Spare	N(H+)	N(O+)	Vsp	Vp-EP	N(E)	2	
13 - 24	RPA I Data (1)	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	
25 - 36	RPA I Data (1)	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	
37 - 48	SM Data	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	
49 - 60	DM-V Data (4)	DM-II Data (4)	DM-V Data (4)	DM-II Data (4)	DM-V Data (4)	DM-II Data (4)	DM-HI Data (4)	DM-V Data (4)	DM-II Data (4)	DM-HI Data (4)	DM-V Data (4)	DM-H Data (4)	DM-H Data (4)	
61 - 72	Multiplex Data	>>>>	>>>>	>>>>	>>>>	>>>>	SM Filters	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	
73 - 84	SM Data	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	
85 - 96	(2) EP I Data (1)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	
97 - 108	(2)EP I Data (1)	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	>>>>	
109 - 120	(2)RPA Sweep V	(2)	(2)	(2)	(2)	(2)	(2)EP	(2)	(2)	(2)	(2)	(2)	(2)	

Table B2 Modified SST/S2 Telemetry Data Format

Word															Cycle
1 - 12	Cycle 1 ID	Config 1 ID	OIS Cmd	Current	RPA Temp	Vap	SM Data 21	SM Data 22	SM Data 23	SM Data 24	EP Monitor	T(E)	1		
	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	
	Cycle 2 ID	Config 2 ID	DSM Cmd	MEP Temp	EP Temp	Vbias					Vp - EP Monitor	N(E)	2		
	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	T(O+)	3		
											RPA Monitor	N(O+)	4		
											-----	-----	-----	-----	
13 - 24	RPA I Data (1)	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	
25 - 36	RPA I Data (1)	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	
37 - 48	SM Data	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	
49 - 60	DM-V Data (4)	DM-II Data (4)	DM-V Data (4)	DM-II Data (4)	DM-V Data (4)	DM-II Data (4)	DM-II Data (4)	DM-V Data (4)	DM-II Data (4)	DM-V Data (4)	DM-II Data (4)	DM-V Data (4)	DM-II Data (4)	DM-V Data (4)	
61 - 72	Multiplex Data	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	
73 - 84	SM Data	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	">>>>>	
85 - 96	(2)EP I Data (1)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	
97 - 108	(2)EP I Data (1)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	
109 - 120	(2)RPA Sweep V	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	

Table B3 SSIES2 MEP Commands

HEX Value	Command	Action	Hex Value	Command	Action
10	Program Re-Set	Re-Start from PROM	33	Set Vbias=3V	
11	Program Re-Start	Re-Start from RAM	34	Set Vbias=4V	
12	Memory Dump		35	Set Vbias=5V	
13	PROM Load		36	Set Vbias=6V	
14	EP Mode A		37	Set Vbias=7V	
15	EP Mode B		38	Set Vbias=8V	
16	EP Mode BS		39	Set Vbias=9V	
17	EP Mode C		3A	Set Vbias=10V	
18	EP Mode D		3B	Set Vbias=11V	
19	EP Mode DS		3C	Set Vbias=12V	
1A	EP Mode E		3D	Set Vbias=13V	
1B	Block Load Start		3E	Set Vbias=14V	
1C	Block Load End		3F	Set Vbias=15V	
1D	Test Mode		40	Set Vbias=16V	
1E	Clock On - CAL Only		41	Set Vbias=17V	
1F	Clock Off -CAL Only		42	Set Vbias=18V	
20	RPA Ion Data First		43	Set Vbias=19V	
21	EP Data First		44	Set Vbias=20V	
22	RAM Test		45	Set Vbias=21V	
23	Set VIP=0V		46	Set Vbias=22V	
24	Set VIP=-1V		47	Set Vbias=23V	
25	Set VIP=-2V		48	Set Vbias=24V	
26	Set VIP=-3V		49	Set Vbias=25V	
30	Set Vbias=0V		4A	Set Vbias=26V	
31	Set Vbias=1V		4B	Set Vbias=27V	
32	Set Vbias=2V		4C	Set Vbias=28V	

Table B4 SSIES2 DSM Commands

HEX Value	Command	Action	HEX Value	Command	Action
80	Normal/H+	DM in Normal or H+ Mode if WIG Mode also sent. Power Up Default	90	DREP00	DM Repeller Pot. = 0.0 V Power Up Default
81	DM FIBA MODE	DM in DM FIBA Mode	92	DREP10	DM Repeller Pot. = 1.0 V
82	WB2AUTO	Free Ranging for DM Wideband Amplifier, Power Up Default	93	DREP15	DM Repeller Pot. = 1.5 V
83	WB2RNG1	DM Wideband Amp Fixed at Range 1	94	DREP20	DM Repeller Pot. = 2.0 V
84	WB2RNG2	DM Wideband Amp Fixed at Range 2	95	DREP25	DM Repeller Pot. = 2.5 V
85	WB2RNG3	DM Wideband Amp Fixed at Range 3	96	DREP30	DM Repeller Pot. = 3.0 V
86	WB2RNG4	DM Wideband Amp Fixed at Range 4	98	0WIGLO	DM H+ Mode, Start Steps at 0 V, Low Wiggle = 50/400 mV (H-DERIV/H+DS)
87	WB2RNG5	DM Wideband Amp Fixed at Range 5	99	0WIGHI	DM H+ Mode, Start Steps at 0 V, High Wiggle = 100/800 mV (H-DERIV/H+DS)
88	WB1AUTO	Free Ranging for SM Wideband Amplifier, Power Up Default	9A	1WIGLO	DM H+ Mode, Start Steps at 1 V, Low Wiggle
89	WB1RNG1	SM Wideband Amp Fixed at Range 1	9B	1WIGHI	DM H+ Mode, Start Steps at 1 V, High Wiggle
8A	WB1RNG2	SM Wideband Amp Fixed at Range 2	9C	2WIGLO	DM H+ Mode, Start Steps at 2 V, Low Wiggle
8B	WB1RNG3	SM Wideband Amp Fixed at Range 3	9D	2WIGHI	DM H+ Mode, Start Steps at 2 V, High Wiggle
8C	WB1RNG4	SM Wideband Amp Fixed at Range 4	9E	3WIGLO	DM H+ Mode, Start Steps at 3 V, Low Wiggle
8D	WB1RNG5	SM Wideband Amp Fixed at Range 5	9F	3WIDHI	DM H+ Mode, Start Steps at 3 V, High Wiggle

Appendix C SSIES3 Telemetry Format

The following is a preliminary description of the SSIES3 telemetry format. The documentation of the SSIES3 system has not been released yet. As much as possible, the SSIES3 format follows the SSIES2 format. For descriptions of parameters in Table C1, the user should refer to the SSIES2 descriptions in Appendix B.

Table C1 SSI/SS3 Telemetry Data Format

Word										Cycle
1 - 12	Cycle 1 ID	Config 1 ID	Cmd Status	MEP HKp	Vap	RPA	>>>>	>>>>	>>>>	1
	-----	-----	-----	-----	-----	-----				2
13 - 24	Cycle 2 ID	Config 2 ID	MEP/ SEP Settings	SEP HKp	-----	-----				
				SEP HKp	Vbias					
25 - 36	RPA Data & Parameters									
37 - 48	SM Data	>>>>	>>>>	>>>>	>>>>	>>>>				
49 - 60	DM Data	>>>>	>>>>	>>>>	>>>>	>>>>				
61 - 72	Multiplex Data	>>>>	>>>>	>>>>	>>>>	SM Filler				
73 - 84	SM Data	>>>>	>>>>	>>>>	>>>>	>>>>				
85 - 96	EP Data	>>>>	>>>>	>>>>	>>>>	>>>>				
97 - 108	EP Data	>>>>	>>>>	>>>>	>>>>	>>>>				
109-120	RPA Data & Parameters	>>>>	>>>>	>>>>	>>>>	>>>>				

Appendix D Relationship of SSIES, SSIES2 and SSIES3 TM Formats

The following table is a map of where parameters are located in each of the telemetry formats. Due to difference between the SSIES and SSIES2 systems, some parameters in one system have no comparable parameter in the other system. The question marks for the SSIES3 format indicate an uncertainty in the correlation of the parameter to the SSIES2 format.

Name	SSIES Word/Cycle	SSIES-2 Word/Cycle	SSIES-2A Word/Cycle	SSIES-3 Word/Cycle
Cycle 1 ID	1/1	1/1	1/1	1/1
Cycle Counter MSB	bit 8 (MSB)	bit 8	bit 8	bit 8
EP Mode	bits 7-5	bits 7-5	bits 7-5	bits 7-5
Test Mode	bit 4	bit 4	bit 4	bit 4
Bias Mode	bit 3	bit 3	bit 3	bit 3
Sweep Clock	bit 2	bit 2	bit 2	bit 2
PRF/Reset	bit 1	bit 1	bit 1	bit 1
Cycle 2 Id	1/2	1/2	1/2	1/2
Cycle Counter Bits 8 - 0				
Config 1 ID	None	2/1	2/1	2/1
RAM/PROM	None	bit 8	bit 8	bit 8
Test/Flt	None	bit 7	bit 7	bit 7
Program Version	None	bits 6-0	bits 6-0	bits 6-0
Config 2 ID	None	2/2	2/2	2/2
RAM Error	None	bit 8	bit 8	bit 8
Dump Flag	None	bit 7	bit 7	bit 7
CheckSum Err	None	bit 6	bit 6	bit 6
Vplink Flag	None	bit 5	bit 5	bit 5
EP/RPA Flag	None	bit 4	bit 4	None
Serial Nbr.	None	bits 2-0	bits 2-0	?None?
CMD. Monitor	70/1.2	3/1.2	3/1.2	?3/2?
OLS/DSM	Bits 7-0	Bits 7-0	Bits 7-0	
T(H+)	101/1	8/1	5/3,7,11	??
N(H+)	101/2	8/2	5/4,8,12	??
T(O+)	110.1	9/1	12/3,7,11	??
N(O+)	110/2	9/2	12/4,8,12	??
T(E)	100/1	12/1	12/1,5,9	??
N(E)	100/2	12/2	12/2,6,10	??
Current Monitor	111/1	4/1	4/1	?3/1?
ADC Temp.	91/2	4/2	4/2	?None?
Electrometer Temp.	91/1	None	None	?None?
DM Elec. Temp.	61/2	62/14,30,	62/14,30.	??
Vap Monitor	81/1.2	6/1	6/1	?6/1?
V(IP/Bias)	90/1.2	6/2	6/2	?6/2?
EP Monitor	80/1	11/1	11/1,5,9	?None?
RPA Monitor	80/2	7/1	11/3,7,11	?None?

Name	SSI ES Word/Cycle	SSI ES-2 Word/Cycle	SSI ES-2A Word/Cycle	SSI ES-3 Word/Cycle
DM LLA	60/1	63/2,6,10	63/2,6,10	?63/2,6?
DM LLB	60/2	63/4,8,12	63/4,8,12	?63/4,8?
Vp - EP	120/1	11/2	11/2,6,10	??
Vp - RPA	120/2	10/1	11/4,8,12	??
Ion Velocity	111/2	10/2	Deleted ?	??
DM Signal Level	61/1	64/2	64/2	??
DM WIBAN2 Range	None	66/2	66/2	?None?
Subcom1	None	61/2	61/2	?61/1?
Subcom2	None	62/2	62/2	?61/2?
DSM Sensor Temp.	None	61/14,30,	61/14,30	??
(D)SM EL/AMP 24 / Sec	2/1,2 - 117/1,2	37-48/1,2 73-84/1,2	37-48/1,2 73-80/1,2 7-10/1,2	37-48/1,2 73-84/1,2
D(S)M Drift 12 / Sec	6/1,2 - 116/1,2	49-60/1,2	49-60/1,2	49-60/1,2
RPA Current	3/1,2 - 118/1,2 24 / Sec	13-24/1,2 25-36/1,2 24 / Sec	13-24/1,2 25-36/1,2 24 / Sec	13- 24/1,2 25- 36/1,2 109-120/1,2
EP Current 24 / Sec	4/1,2 - 119/1,2	13-24/1,2 25-36/1,2	13-24/1,2 12-36/1,2	85- 96/1,2 97-108/1,2
SM Filter	10/1,2 - 50/1,2 9 / Sec	67/1,2 - 72/1,2 6 / Sec	67/1,2 - 72/1,2 6 / Sec	67/1,2 - 72/1,2 6 / Sec
DM Filter 6 / Sec	None	61-66/1	61-66/1	None
VBias/SENPOT Flag	70/2 bit 8	1/1 Bits 7-5 (See EP Mode for SSI ES2)	1/1 Bits 7-5	??
VIP Setting	90/all bits 7-6	6/2 bits 7-6	6/2 bits 7-6	??
VBIAS Volts	90/1,2 bits 4-0	6/2 bits 4-0	6/2 bits 4-0	??
DSM Command	70/2 bits 7-0	None	None	None

Name	SSIES Word/Cycle	SSIES-2 Word/Cycle	SSIES-2A Word/Cycle	SSIES-3 Wordd/Cycle
EP Monitor	80/1	11/1	11/1,5,9	??
RPA Monitor	80/2	7/1	11/3,7,11	??
EP Sweep Monitor	5/1,2 - 105/1,2	None	None	?62/1,2?
RPA Sweep Monitor	15/1,2 - 115/1,2	None	None	?64/1,2?
Test Outputs	71/1,2	None	None	?None?
RPA/EP Thermistor	None	5/1,2	5/1,5,9 5/2,6,10	Subcom

Appendix E Acronyms, Abbreviations and Nomenclature

°K	Degrees Kelvin
AFGL	Air Force Geophysics Laboratory (former name of PL/GP)
AFGWC	Air Force Global Weather Central, Offutt AFB, NE
AFSFC	Air Force Space Forecast Center, Falcon AFB, CO
AWS	Air Force Air Weather Service
cm	Centimeter
corotation	The movement of the atmosphere/ionosphere at the same angular velocity as the surface of the Earth below a given location.
DM	Ion drift meter, part of SSIES, also referred to as the IDM
DMSP	Defense Meteorological Satellite Program
DSM	Electronics box in SSIES system which controls DM and SM
e	Electronic charge on one electron or proton = 1.602×10^{-19} coulombs
eV	A unit of energy equal to the energy of a particle with one electronic charge after falling through a potential of 1 Volt; = 1.602×10^{-19} joules
ELEC	Spherical Langmuir probe for collection electrons, part of the SSIES, also referred to as the EP
EP	Spherical Langmuir probe for collection electrons, part of the SSIES, also referred to as the ELEC
EPROM	Erasable, Programmable Read-only Memory (a computer chip or set of chips)
GPS	Global Positioning System
IDM	Ion drift meter, part of SSIES, also referred to as the DM
IMF	Interplanetary Magnetic Field - the portion of the Sun's magnetic field which stretches out into interplanetary space.
keV	10^3 electron volts
km	Kilometer.
Kp	Indicator for Planetary Magnetic Activity during a 3-hour period
LSB	Least significant bit of a computer word
MEP	Electronics box in SSIES which handle power supply, TM output and control of EP and RPA
MP	Microprocessor system for the SSIES
MSB	Most significant bit of a computer word
n.mi.	Nautical mile (= 1.852 km.)
NGDC	National Geophysical Data Center, Boulder, CO, USA
NOAA	National Oceanographic and Atmospheric Administration
OLS	Operational Linescan Imager System (primary instrument on DMSP spacecraft)
PL	Phillips Laboratory
PL/GP	Geophysics Directorate, Phillips Laboratory, Hanscom AFB, MA
PL/GPS	Space Physics Division, Geophysics Directorate, Phillips Laboratory
PL/GPI	Ionospheric Effects Division, Geophysics Directorate, Phillips Laboratory
PMP	Precision Mounting Platform (a section of the DMSP spacecraft)
PRISM	Parameterized Real-time Ionospheric Specification Model (a computer program)
Re	Earth Radii = 6376 kilometers = 3443 nautical miles
RAM	Random Access Memory (a computer chip or set of chips)
RPA	Ion retarding potential analyzer, part of the SSIES.
RSTN	Radio Solar Telescope Network
SEP	Electronics box of SSIES3 containing electronics controlling all sensors.
SM	Total ion trap, part of the SSIES.
SOON	Solar Optical Observing Network
SSBX	X-Ray Scanner System on DMSP spacecraft
SSF	Laser Warning Receiver System on DMSP spacecraft
SSIES/	Topside Ionospheric Monitor System on DMSP spacecraft (configuration 1, 2 and 3)
SSIES2/SSIES3	
SSJ4/SSJ5	Precipitating Ion and Electron Spectrometer Sensor System on DMSP spacecraft
SSM	Fluxgate, Vector Magnetometer Sensor System on DMSP spacecraft
SSMI	Microwave Imager System on DMSP spacecraft

SSMT1	Microwave Temperature Profiler System on DMSP spacecraft
SSMT2	Microwave Humidity Profiler System on DMSP spacecraft
SSN	Sunspot Number
SSULI	Limb-Scanning Ultraviolet Imager Sensor System on DMSP spacecraft
SSUSI	Nadir-Scanning Ultraviolet Imager and Spectrometer Sensor System on DMSP spacecraft
SSZ	Laser Threat Sensor System on DMSP spacecraft
TEC	Total Electron Content
TISS	Topside Ionospheric Sensing System (a digital ionosonde system)
V	Volts, unit of electronic potential.
VSH	Vector Spherical Harmonic model (a computer program)